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Creating Systems of Innovation in Africa

Country Case Studies

Edited by Mammo Muchie and Angathevar Baskaran

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Creating Systems of Innovation in Africa: Country Case Studies

Edited by Mammo Muchie and Angathevar Baskaran



Creating Systems of Innovation in Africa: Country Case studies

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DEDICATION

Mikael and Adey Muchie and all the children of
Africa to stand up and innovate a strong, free,
confident, independent and proud Africa.

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Preface

The South African Research Initiative (SARChI) started the research applying the innovation systems theory approach to African problems of development and structural transformation since 2008. Throughout the last four years the SARChI chair has concentrated research on innovation to address the challenges of African development inspired by the vision that Africa's bright future is better created by making it rather than predicting a destination to reach at some unknown date.

The SARChI started the African Journal of Science, Technology, Innovation and Development in 2008 and we have published four issues every year, it is the expectation that six issues will be published in 2013 with Taylor and Francis publishers. This has been an important outlet for emergent African researchers as nearly 70 per cent of those who publish in the journal are Africans both in Africa and abroad. The objective is to create a publishing outlet in Africa with ISI listing This will enable researchers to produce and publish research papers that are peer reviewed with high impact factors. The African Journal of Science, Technology, Innovation and Development is firmly on track in achieving the recognition and rating that will make it sustainable. It is one of the key milestones of the DST/NRF Research chair in innovation and development that Tshwane University was offered. The journal has a website: www.ajstid.com

This book series is another milestone of the SARChI chair initiated. This volume has the distinction in 2012 of being the first to start the production of a series of books on the systematic application of the innovation system approach to the challenges and opportunities of accelerating and fully realising the creation of an African national innovation system. The application of systems of innovation framing and theories to African problems of development is still new. The field has been dominated by development studies. This book series offers an alternative by proposing systems of innovation approach to generate knowledge, learning and competence building in Africa as a primary highway for Africa to make the development journey into the future.

In the African context, the combination of innovation with development is a big challenge. It is not easy to do it. The main reason is that Africa's economic development has been constrained by the load it still suffers from the colonial legacy. The states as they exist are divided and when they form regions, they still remain divided. There are claims that Africa's fortunes are changing and conflicts are decreasing. There are some economies that are growing by over seven per cent. Democratisation is slowly and surely

growing. Technologically mobile phone users are growing and the ICT revolution in Africa may help Africa to leapfrog and join as a player rather than a victim of the division of labour in the world economy. There is a need to appreciate that the key to Africa's development remains the ability of Africa to create a united African economy. The existing states or the regions they suffer from a formidable deficit, that is, failure to 'Put Africa First' and failure to formulate a united policy and strategy to deal with the colonial legacy and the new and current challenges Africa is facing today. Therefore the book series articulates and highlights the research needed on African innovation and development at various levels to demonstrate what would work most effectively in the specific African context and ultimately create an integrated African system of innovation.

Mammo Muchie and Angathevar Baskaran

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Introduction

Mammo Muchie and Angathevar Baskaran

There are different approaches to the system of innovation building process. There is the linear traditional route, and there is also the co-evolution route. The linear route in the African development context today sees progress from agriculture to manufacturing. Co-evolution sees agriculture co-evolving with manufacture; the rural economic sector co-evolving with the urban sector, the community with industry, university and Government. The challenge of African structural transformation is to convert from a predominantly rural condition to an industrial manufacturing social-economy. The system of innovation approaches the problems of transformation as a knowledge, learning, innovation and competence building dynamic and challenge. If we go for co-evolution, the community has to enter as a helix to join all the other key actors such as Government, university and industry. There is a need to create a locally centred community system of innovation to address the rural world in Africa, where the majority of the people live. The community system of innovation can be framed to define the learning, knowledge, innovation and competence building levels needed to mobilise resources, organise knowledge, human capital training for deploying institutions, putting in place incentives and regulations to carry out favourite experiments on activities and functions that are undertaken by citizens at grassroots levels in local areas. The framing of a community or local level system of innovation opens up the opportunity to harvest the indigenous knowledge, both tacit and explicit, that exist in the local communities to have economic value by turning them into innovation. The notion of turning rural communities into innovative, learning and competence driven economies turns them into exist as modernised rural communities rather than turning or transforming necessarily as mainly urban and industrial entities. The innovation system has to be broadened and has to include not only profit maximising objectives, but also human well-being and sustainability goals and purposes. Innovation has to be locally adapted, embedded and socially inclusive.

But the most popularised concept in the economics of innovation literature has been the national system of innovation (NSI). It is in the late 1980s that the concept that Frederik List coined as the National Political Economy of Production took off again with different thinkers applying writing about the peculiarities and distinctions of the Japanese, American, British, German, East Asian Tigers and other varieties of system construction. Freeman (1987), defines National System of Innovation as 'The network of

institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies.¹

Richard Nelson defines it as: 'A set of institutions whose interactions determine the innovative performance.. of national firms.'²

Lundvall defines the system of innovation as the 'elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge... and are either located within or rooted inside the borders of a nation state.'³

The normative assumption is that those nations that succeeded in building economic strength relied on the science, engineering, technology and innovation capability that made them to achieve an innovation advantage to put them ahead in the world, acquiring national or regional economic leadership as the case may be depending on what level of analyses is selected to look at particular failure, success or progress they made.

The application of innovation systems to economies that barely can claim of setting up any system to speak of, in the sense that what is normal is the interaction of system elements with incoherence rather than system of innovation coherence, is a challenging intellectual and research enterprise.

There has been interest to apply the national innovation system to developing economies.⁴

In the developing economy context, the challenge is to excavate and explore how system of innovation elements with their dynamics of interaction can show emergent properties that exhibit a degree of coherence that can meaningfully and sufficiently permit their characterisation as showing properties of system emergence. If it can be ascertained that from system incoherence or chaos they can evolve into emergent system coherence, then the next logical step is to ask whether or not the emergent system can also move along the trajectory of innovation system take-off. If there is a merit to the system of innovation take-off, then, the opportunity for dynamic state of innovation system build-up towards maturity will be open. This kind of linear thinking is prevalent in a world where the rule of the game is fierce competition among states, nations, firms, countries and economies with different degrees of system coherence and incoherence built into the logic that drives the pursuit of their self-interest.

The interesting question is whether or not in Africa the opportunity can be open to stimulate both economic and social innovation and make them co-evolve without compressing the social with the economic or slowing the economic by the explicit inclusion of the social. The transformation challenge is to be able to combine both social and economic development in Africa.

After the questioning of the linear route of economic development, there have been a number of novel approaches that have been introduced. Some

of them are: building systems of innovation for smart economic growth; systems of innovation for inclusive growth; systems of innovation for justice fairness and equitable distribution of resources to enhance the welfare of people starting from the least advantaged; systems of innovation for poverty eradication; systems of innovation for sustainable development; systems of innovation that overcome irrational fragmentations and help construct a project identity; systems of innovation that can combine modern scientific knowledge with indigenous local knowledge; systems of innovation capability for knowledge exchange rather than for knowledge transfer from those with strong systems of innovation to those with very weak systems of innovation and so on. What would work better, promoting system of innovation based on broad-based innovation or system of innovation with high technology content, or combining them together to create new synergies and syntheses? The application of the science, technology, engineering and innovation perspective in reinterpreting the African development comes against these varieties of approaches that make both prioritising and selecting what to be undertaken very challenging.

A key challenge is how to create a dynamic economy where agriculture and industry and services are integrated. The integration also is accomplished by promoting science, technology, engineering and innovation so that transformation and dynamic change become a reality as a consequence. Can this be best promoted by developing a co-evolutionary dynamics of agriculture with manufacture and services or by taking the existing division of labour and a linear route of change from agriculture through economic growth take-off?

The contributions in this volume partly address some of these pertinent questions. What they demonstrate is how much research still needs to be done by exploring partially some issues that highlight the critical importance of linking science, technology, engineering and innovation to African economic development.

The chapter by Robert Joumard and Ménouër Boughedaoui explores the research typology and knowledge needs for development in Africa.

The authors suggest that the management of scientific activities efficiently with the aim of development requires that their objectives, methods, roles and their links are clarified. They include what they describe as the targeted societal research for decision-making in addition to the three usual research types: Basic research; applied research and experimental development. The relevant contrast appears to be less between basic research and experimental development, or between government-driven and society-driven research, than between market-driven research and public-service research. The knowledge economy promotes useful research with a technological purpose, which marginalises the knowledge production that

could allow the citizens as the societies to revitalise and redefine themselves, and to answer the present challenges. The authors propose some tracks to strengthen research-developing capabilities in Africa.

Jo Loretzen explores what is wrong and right about Ghana's Innovation System. Science, technology and innovation (STI) are expected to play a key role in lifting Ghana to middle-income status by 2020. Ghana is not alone in wanting to promote STI as a means to socio-economic development; governments throughout Africa have been making political commitments in support of the knowledge economy. The author provides a micro-assessment of the Ghanaian national innovation system (NIS) and in particular of the role of the public research institutes and the three oldest and largest universities. It addresses the adequacy of public funding for the system along with its scientific and technological output and finds both below par. He found that the reasons for underperformance lie further in the management of human resources, underdeveloped and badly understood institutions, widespread coordination failures, a lack of reflexivity, and a general absence of effective linkages between the various elements of the system. The author recommends and highlights success stories that illustrate the untapped potential of the NIS and suggests how the system could be improved.

Geoffrey Gachino uses firm-level panel data from Kenyan manufacturing industry to compare labour productivity, export and skills formation between foreign and local firms. He demonstrates the superior productive capabilities and market access of multinational firms, foreign direct investment (FDI) that appear to enjoy greater potential to generate labour productivity, manufactured exports and skilled labour than local firms in poor economies. He examined how FDI affects labour productivity, export and skill formation as one of the determinants, among others. The results generated show that, although local firms generally fared better than foreign firms involving the growth of labour productivity, exports and skilled labour, foreign firms continued to enjoy higher shares. FDI had a positive relationship with labour productivity, exports and skill formation. Overall, it can be claimed that FDI has generally impacted positively on Kenyan manufacturing labour productivity, exports and skilled labour. The positive results of positive impact of FDI have been obtained despite low levels of FDI. The implication is that FDI should be promoted but in tandem with domestic industrial policies which ensure enhanced learning, capability development and innovation.

Abolaji D. Dada, Godwin A. Ali, Oladele O. Afolabi, and Williams O. Siyanbola explore innovative approaches to industrial utilisation of cassava in a developing economy. Nigeria has remained the world's leading economy in the production of cassava for about two decades. Nevertheless, the industrial utilisation of this agricultural produce has remained low. The

authors synthesise the findings of an extensive literature on some innovative approaches to this challenge. There is a need for policy learning on how Nigeria can sustain global leadership in cassava production by an efficient utilisation of cassava in the industrial sector to transform the Nigerian Small and Medium Enterprises (SMEs). The Nigerian government is encouraging private sector participation in developing technologies for expanded use of cassava as raw materials in the food and non-food industries. The development of the sector will require activities in capacity building, further product development, fabrication and transfer of processing technologies to target beneficiaries, and development of clusters to supply identified markets. To sustain Nigeria's global leadership in cassava production, the authors suggest the need to map out the cassava value chain in the cassava sectoral innovation system.

Kiggundu Rose explores the question of how to enhance innovation in developing countries by taking cases from Uganda in order to make a contribution to an improved empirical understanding of the nature of innovation system competence building in Africa. After a framework of analysis for assessing system competence building is defined and applied to five case studies drawn from Uganda, the author draws from the case studies three appreciative empirically grounded system building typologies. The findings show evidence of types from the case studies that continues to be organised to introduce new knowledge and innovation and strengthen research and technology systems. It appears that other kinds of system building have received far less attention. A comparative analysis of case studies reveals important sectoral and spatial specificities which help to explain why within a national system of innovation, the same approach successfully employed to build competences in one specific sector or geographical location may not have the same effect elsewhere. There is still a long way to go before all relevant actors acquire a full understanding of what it would take to build functional systems of innovation and the competences required.

Abdelrasaq Al-Suyuti Na-Allah and Mammo Muchie in their firm-level analysis of technological externality of foreign direct investment in South Africa examines how foreign direct investment (FDI) impacts on productivity performance in host economy by raising and addressing two key questions: (a) To what extent does technological externality of FDI (FDI spillover) rely on host economy's skill deficiency characteristic before it can be generated and appropriated? (b) Is there a regional dimension to the level of spillovers from multinationals to domestic firms? Using establishment level data for the South African economy, they estimate regression equations for a representative sample of South Africa's manufacturing plants. Their findings reveal that regardless of the environmentally imposed skill deficit factor, foreign firms are able to generate productivity spillovers for their host. Successful

diffusion to domestic firms is however mediated and significantly circumscribed by the skill factor. It also appears that some support exists for the claim that level of FDI spillovers to domestic firms relies on regional presence, i.e. closeness to the region in which foreign firms locate.

Kassim S. Mwitondi and Khamza K. Maunda discuss the patterns and predictability of various types of cancer. They found that comparative studies on geo-ethnic grounds (particularly Africa-specific) have been quite limited. They critically examine the common methods used in studying cancer predisposing factors and propose a novel triangular approach to detecting patterns in data samples. Three samples of cervix cancer, conjunctival cancer and Kaposi's sarcoma, collected from various regions in the United Republic of Tanzania, are subjected to techniques for graphical visualisation (GDV), association rules (AR) and dimensional reduction (DR). They discover interesting patterns in the distribution of the three cancer types hinging on Tanzania's basic cultural attributes and geographical diversity. Their findings show that the triangular approach is capable of uncovering subtle cultural-driven relationships among data attributes. The findings present a basis for assessing and evaluating the impact of predisposing factors on the three types of cancer hence providing some useful guidelines into informed intervention, prevention and treatment of the diseases. The authors make recommendations as to how to structure future cancer studies in areas of similar geo-ethnic features. The triangular approach to extracting knowledge from data provides insights into avoiding knowledge masking effects and highlights the need for formulating and designing a prototype model for updatable cancer-related data sources and storages aimed at connecting cancer registries across the African continent and beyond.

CONCLUDING REMARKS

The systems of innovation in each state in Africa is still waiting to be explored. It remains whether the national is real or not in the sense that policies made by the states have measurable impact to the impact of innovation in the local economy.

It remains also a real issue how far systems have been forged in the process of constructing how science, technology, engineering and innovation can bring about a transformation logic to the national economy.

It also remains important how far the innovation is part of the culture in bringing about economic transformation in the given economy.

In this volume we have a glimpse of how in different African economies from Ghana, Uganda, Kenya, South Africa and Nigeria specific cases have been taken to explore how systems of innovation is evolving.

What the contributions demonstrate individually and as a group is how important it is to continue this research to continue the journey to produce work that is much needed in undertaking rigorous research to move beyond putting 'innovation system as an issue in the African (development) agenda.'⁵ What is needed now is to apply innovation systems to find new approaches to structurally transform the African social economy. The cases in this volume go a long way to practically address this research demand.

NOTES

- 1 Chris Freeman, C., 1987, Japan, a New System of Innovation, in G.Dosi, C. Freeman, R. Nelson, G.Silverberg, and L.Soete(eds.), *Technical Change and Economic Theory*, London; Printer Publishers.
- 2 Nelson, R., and Rosenberg 1993. *Technical Innovation and National Systems*, in R. Nelson(ed.), *National Innovation Systems: A Comparative Analysis*: New York, Oxford: Oxford University Press.
- 3 Lundvall, B. (ed.) 1992, *National Innovation System. Towards a Theory of Innovation and Interactive Learning*, London: Pinter Publishers.
- 4 Lundvall, B.A., Johnson, B., Anderson, E.S., and Dalum, B.(2002), *National Systems of Production, Innovation and Comptence Building*, *Research Policy*, 2, pp.213–231.
- 5 Muchie, Gammrtolft and Lundvall (eds.), *Putting Africa First: The Making of African Innovation Systems*, 2003, Aalborg University Press, Denmark, p8.

Research Typology and Knowledge Needs for Development in Africa

Robert Joumard and Ménouèr Boughedaoui

SUMMARY

The efficient management of scientific activities with the aim of development requires that their objectives, methods, roles and their links are clarified. In addition to the three usual research types: Basic research; applied research and experimental development, the targeted societal research for decision-making is presented with its specificities. The relevant contrast appears to be less between basic research and experimental development, or between government-driven and society-driven research, than between market-driven research and public-service research. The open knowledge plays here a fundamental role in the evolution of the societies and in their development. The knowledge economy promotes useful research with a technological purpose, which marginalises the knowledge production that could allow the citizens as the societies to revitalise and redefine themselves, and to answer the present challenges. Eventually, we propose some tracks to strengthen research-developing capabilities in Africa.

INTRODUCTION

“If we are to take measures that will make a genuine difference to the lives of the 800 million people in Africa, to future generations and the environment upon which so many depend, we need sound and solid science,” according to A. Steiner, UNEP Executive Director and United Nations under-general secretary (UNEP, 2006: xxiii). And Darnton (2009: 1) stated that “our [US] republic was founded on faith in the central principle of the eighteenth-century Republic of Letters: the diffusion of light”. But for instance at the African level, firstly at the “Science with Africa” conference organised by UNECA in March 2008 in Addis Ababa, the various themes (presentation of

research findings, analysis of research conditions, research policies) were essentially all given equal importance: There was a lack of a clear analysis, and even an understanding, of what is research and what is not; of what sets it apart from other human activities. Barely any distinction was made between research, sciences and activities involving scientific knowledge. It is hard to manage these activities efficiently when their characteristics are not known. The preparatory documents for the CODIST I conference¹ give the same impression as well: The terms “science”, “technology” and “innovation for development” are typically used together, as if they covered the same thing. This is akin to the opinion of Müller (2009) about the United Nations’ Food and Agriculture Organisation (FAO): It thinks that corporate interests drive innovation, that innovation is positive, and that intellectual-property rights are required to stimulate innovation; progress is good because it progresses. What is remarkable about the vision of scientific progress is that the FAO conceives of progress as a “progression” that does not necessarily have a destination. The affirmation in the CODIST I concept note (UNECA, 2008) of a univocal link between experimental development and development is, we feel, equally open to criticism.

Likewise, a distinction must be made between research activities and studies and consulting activities. To ensure clarity of debate and efficiency of actions undertaken, one must define the outlines and activities of research, study and innovation: What are their objectives, methods and roles? How are they different and complementary? In what conditions are they conducted? Who are the stakeholders and participants?

More generally, research, science, innovation and development, and how they inter-relate, must be analysed by adopting a viewpoint that is critical in the scientific meaning of the word, i.e. by evaluating their positive and negative aspects and their contradictions as well.

To discuss these arguments, we focus above on the different types of research, from the basic to the societal research, positioning their relationships with experimental development and innovation. We highlight the societal research for public decision in knowledge society. Then we discuss the meaning of knowledge economy in terms of innovation and open access to knowledge, and the link between scientific activities and development. We propose some ways to strengthen research-developing capabilities in Africa.

DIFFERENT TYPES OF RESEARCH

There are different types of research: Basic research, applied research, experimental development and societal research.

BASIC RESEARCH, APPLIED RESEARCH, EXPERIMENTAL DEVELOPMENT

We will first try to discuss the end goals and processes of research. The contrast between basic research and applied research often structures debate, but we feel that this typology is simplistic and does not reflect current challenges. Basic research, applied research and experimental development are the three types of conventionally recognised research, as defined by the Frascati manual, though the boundaries of classification are by nature hazy and permeable (OECD, 2002).

The concept of basic research is by far the best defined. Its purpose is to understand and explain all phenomena and observable facts, or to identify and understand the mechanisms behind the phenomena as it is observed by the researcher, without any particular application or use in view. Its applications and findings are uncertain, its deadlines are unpredictable but always far in the future, and its profitability is random. Its findings belong to human heritage, and so cannot be patented (even though some have tried). Consequently, it receives mainly public funding.

Conversely, experimental development leads to the conception of pilot schemes and to the industrial and commercial implementation of research outputs, which can often be patented. It is essentially funded by the private sector, and its outputs belong mainly to investors.

The boundaries of applied research – which is neither basic nor experimental development – are quite poorly defined in the daily research world. Sometimes, research is said to be applied simply because its area of application is precisely scoped, without this specifying how the research operates; for example, research will be described as being applied to transport or agriculture. In this case, it is called oriented basic research by OECD. Most often, applied research is defined as an extension of the discoveries of basic research: Understanding new mechanisms through the latter can lead, in a totally unpredictable way, to new applications in terms of technologies or services, whose development is the purpose of applied research. Applied research then aims to acquire new knowledge in order to resolve practical and tangible problems or to develop applications, goods and services. Its findings are often considered patentable, and it is primarily conducted by the private sector.

The taxonomy of basic research versus applied research is sometimes easy to apply. Reynolds (1998) defines basic research as the foundation of the knowledge base upon which decision-makers rely whilst applied research tends to seek the cause and remedy for an immediate issue.

In biology, basic research will seek to understand a cell mechanism; applied research will possibly develop a drug based on the newly-discovered cell mechanism. In physics, basic research was done on the

energy levels of elemental particles; then, with this new knowledge, applied research developed the laser. In the field of mathematics, basic research into algorithmic led to applied-research extensions in the area of encryption systems.

Basic research therefore seems to be the essential foundation for applied research as thus defined. The distinction may even appear artificial, given that one cannot exist without the other. In particular, they are linked by a spiral: Discovery of a basic mechanism, which is used to develop a new practical application, which allows new advances in basic research, and therefore the discovery of new mechanism. Denny (2001) reported that developing countries consider there is rather a need for studies on immediate every day problems than curiosity-driven research. It is more appropriate for industrialised and rich than poor countries. Lack of basic research, nevertheless, leads to a poor knowledge and expertise capacity of the nation.

TARGETED SOCIETAL RESEARCH FOR PUBLIC DECISION-MAKING

The concept of targeted research has emerged more recently: Unifying basic research and applied research, it arises from social needs and is commissioned to resolve a concrete issue (Barré, 2004, Joumard *et al.*, 2004, Pestre, 2004, Jollivet and Legay, 2005). It is called mode-2 science (Gibbons *et al.*, 1994, Nowotny *et al.*, 2001) or post-normal science (Funtowicz and Ravetz, 1991, 1995, 1997, Luks, 1996, 1999, Funtowicz *et al.*, 1997).

The human sciences contain many examples of such research. To take examples from the field of transport: In psychology, understanding human behaviour in driving situations; in sociology, understanding users' modal choices; in geography, identifying laws that govern spatial phenomena such as urbanisation and transport flows. This research is defined as a response to concrete societal questions, implementing the principles of theoretical research, but with constant interaction between field and theory that promotes an understanding of both.

The societal aspect of this research does not necessarily refer solely to the human and social sciences. Research on emissions of atmospheric pollutants by road transport has in the past 20 years highlighted essential parameters such as vehicle operating conditions (speed, gradient, ambient temperature, etc.) and the composition of vehicle fleets. In the field of rail safety, research has shown the importance of maintenance procedures and their optimisation, evaluated in terms of overall transport-system efficiency and not only of short-term profitability. In the environment field, work on the hierarchy of the physical and chemical causes of declining ecological quality of watercourses will allow better organisation of the measures

needed for watercourse restoration and the health of local populations. In public health, at-risk groups or risk factors are identified for a given health event in order to choose action priorities according to very non-commercial criteria that are extremely important in citizens' minds (for example, the premature death of the elderly). In agronomic research, recent work has diagnosed the flaws of the dominant production-based system by demonstrating that it is possible to reconcile the profitability of agricultural production with environmental protection. However, designing economical and autonomous systems is scarcely compatible with the short-term economic interests of a sector that lives on largely by selling, and even importing, inputs and exporting goods.

This research therefore produces knowledge and explanations of a public, and even social, phenomenon. It often involves measuring and modelling a phenomenon in given spatial and temporal circumstances, and quantifying the role of an influential parameter in order to support the decision-making process (the concept of research for public decision-making is often used).

A second characteristic arising from this type of research is that its findings can immediately be commented upon by all, because the phenomenon under study is a public, social object and the concepts are very similar to mainstream concepts, especially if one bothers to translate the jargon. The fact that everyone can talk about it does not mean, however, that everyone talks about it properly. This is the strength and the difficulty inherent in this type of research. For instance, in the transport-environment sector, citizens highlight the role of congestion, but research highlights rather the role of increasing trip length, the congestion playing a positive role by decreasing the traffic demand.

Lastly, a third characteristic is that this research can be applied almost immediately (if one excludes power-related phenomena and multiple change-resistant factors) and can improve society's mode of organisation by minimising its environmental impact or the risk of accidents or deaths, to repeat the examples given above. The research is not typically applied in the market economy, and therefore does not receive the accelerating boost that profitability gives to a private-sector company. It must be the subject of a collective, political decision.

It is obvious that the basic/applied research typology no longer holds true: In these fields, the characteristics of research activity differ radically from those of basic research, although they are not part of the spiral which links applied research and basic research or in a continuum that adds economic value. This spiral, previously autonomous, is being challenged by the introduction of a major stakeholder: The society as a whole, with its representatives and lobbies. In the environmental field, researchers have

highlighted multiple impacts of human activities on the environment, which has helped drive the emergence of social concern about environmental issues and then about the problem of the nature-society-economy schematic of sustainable development, which itself guides research activities, which, in turn, will doubtless yield new social concerns...

In summary, the characteristics of this research, which we prefer to term societal rather than targeted, which is too vague a term, could be:

- Social utility: Its applications are essentially in the field of the collective management of our society, and are not directly market-based. The current debates about sustainable development are one of its most accomplished expressions;
- The non-patentability of its findings, even though the tools developed to obtain these findings can add value and/or be transferred into the market sphere;
- The independence of research authors, which must be ensured by their status, and which alone can guarantee the defence of the collective interest through non-subjection to market interests;
- The highlighting of strong relations between the phenomenon studied and parameters that are generally already known, and which are quantified and categorised in a hierarchy;
- Its transversal, often multi- or trans-disciplinary character, not only drawing on disciplinary contributions, but also by setting up new frameworks beyond them (Funtowicz and Ravetz, 1995; Gibbons, 2000), which cannot be reduced to the concepts of basic and applied research;
- The natural insertion of its findings into public conversation, from the village square to society's big debates;
- It is essentially publicly funded, because of its first three characteristics.

The relevant contrast, therefore, appears to be between commercial or market-driven research and public-service research not mediated by the market. It is not thus between a knowledge production system driven by government and academic community on one side and by the civil society on other side, understood to comprise individuals and groups. This last picture forgets the imbalance between the stakeholders with financial, social, cultural and expertise resources, and those without (Saurugger, 2003).

In addition, societal research has the distinctive feature of often developing without, and sometimes against, scientific-research institutions, particularly in so-called alternative fields (organic agriculture, renewable energies, etc.). Some non-governmental organisations are now scientifically

more competent than public institutions. In parallel, a rise can be seen in the scientific expertise ability of civil society; this emerging field forms science's third sector.

Societal research experiences the same funding and support problems as basic research. It generates little private profit through directly-patentable applications; its primary target is collective benefit, which may be against corporate logic. It should be steered by the research stakeholders themselves, in association with social demand. Peer review in accordance with appropriate criteria provides the necessary guarantees of research quality, but it includes a wider, more temporary and heterogeneous set of practitioners, collaborating on a problem defined in a specific and localised context (Gibbons, 2000). The short-termism of big corporations' steerage and the opaqueness of direct steerage by ministries and foundations can be a strong barrier to its development. Africa has to develop its own approach for scientific research based on the African culture and environment to respond to African priorities and solve their own problems and to address people's needs (Stigter, 2006).

DISSEMINATED KNOWLEDGE SOCIETY

Society's research needs must also and especially include the production of public goods: Open knowledge, plural and independent expertise, and non-profit innovation or innovation meeting non-solvent societal needs. However, the production of socially-useful knowledge and innovations is no longer the preserve of traditional public or private research institutions; it is also performed by the emerging third sector of knowledge and innovation, i.e. by multitudes of collectives (patients, farmers, consumers, peer-to-peer digital communities, etc.) which collectively take charge of producing scientific and technical knowledge and must be recognised as equally legitimate partners in public research. In this case, the term used is "disseminated knowledge society", which marks the entry into a finite world where science has a new role to play (precautionary principle, sustainable development). There is thus a need for innovation and research policies to promote clear social and environmental priorities and global concerns.

In this third sector, local communities in Africa also create knowledge and must therefore play a central role in creating local content. Local knowledge spans farming, wildlife and environmental management. The oral tradition is important in Africa as the main way of transmitting knowledge, which is memorised through different generations. Access to local knowledge is difficult for various reasons, especially the low level of development of institutions in most African countries (Raseroka, 2007: 13). As emphasised by the participants in CODI V (UNECA, 2007: 14), there

is a need for wider availability and use of traditional and local knowledge, with universities, especially their libraries, being actively involved in the processing and dissemination of this knowledge.

Societal research is what creates the link between scientific knowledge and the multiple facets of society's organisation. It meets society's demand for better self-understanding, by incorporating the findings of basic research and of experimental development, and even by developing such research if necessary. Research findings have to be communicated in an understandable terms to government, general public and to local communities (Denny, 2001). It is therefore essential in guiding the decisions of the individual, the citizen and the elected representative. It is an essential constituent of democratic transparency.

THE KNOWLEDGE ECONOMY

The knowledge economy is now presented as the new paradigm of science, economics and development. It is defined as the economy in which knowledge is perceived as an essential resource and a factor of production, but also the economy in which knowledge is the main driver of economic growth. It is characterised by four main pillars: Innovation, investment in experimental development, human capital development, and incentives and legislation (Tapper, 2007: 10).

The knowledge economy closely combines two aspects that we will now discuss in turn: The growing importance of knowledge and its dissemination using new information and communication technologies (ICTs), and their partial privatisation.

KNOWLEDGE AS AN ESSENTIAL RESOURCE

According to A. Janneh (2007), UNECA Executive Secretary, the current global society is driven by information and is characterised by knowledge-intensive industries and services, comparative advantage, and economic success being increasingly based on the effective utilisation of intangible assets such as knowledge, skills and innovative potential. Africa risks losing a high percentage of its human resources through a brain drain to countries where the knowledge industry is more developed. Although it is accepted that knowledge plays an essential role in success and that the brain drain is real, this statement has two flaws:

- It is far from certain that knowledge is playing a more important role than before. The industrial revolution in Europe and North America

was based on the Enlightenment, rationalism from Descartes to Kant, and scientific creativity in the 19th and 20th centuries.

- Referring only to industries and services in the dynamic of global society masks the essential role played by public services of all kinds, in particular by public education, university, public research, libraries and other public systems of information and culture, which actually absorb most of the exodus of African minds.

According to Amable and Askenazy (2005), the recent attention paid to the knowledge economy stems from the growing importance of research and education activities in the global economy. This rise in knowledge-intensiveness also concerns the associated ICTs. But it would take boundless technological optimism to conclude that the dissemination of these technologies can help countries in the South to catch up with those in the North. The dissemination of these techniques can only be considered as a complement to organisational, cultural and behavioural changes, and, in particular, to the improvement of individuals' skills. One of these elements, transplanted into a different context, is not in itself enough to trigger a virtuous dynamic.

The articulation or interconnection of the physical, technical, social, cultural and even psychological aspects highlights the need for a systemic approach. The idea is not for each person to be competent in everything. The idea is, for each person, at least in the knowledge-rich sphere, to have a wide and multi-disciplinary scientific culture, and for a problem to be analysed with a range of approaches that cover the various aspects of the system.

This leads us to reflect on knowledge and how it is disseminated.

Knowledge is a good that is hard to control, unrivalled and cumulative (Vincente, 2003). The first regime for incentivising knowledge production is creating a market to restore private initiative. It aims to restrict access to knowledge by granting temporary exclusive rights to new knowledge. The second regime is public: Open knowledge, with the circulation of codified knowledge, practical knowledge, and research instruments. The world of closed knowledge is a semi-permeable world that makes cooperation difficult. The idea of closed knowledge is closely associated with intellectual-property rights (copyright and patent rights). Policies that help to weaken open-science institutions may prove counter-productive in the long term.

It is obviously important to encourage the use of new ICTs in order to reduce the digital divide within African countries and between Africa and other regions, but especially because it is an extraordinary vehicle for exchange, culture, education and information, and therefore for accessing and disseminating knowledge. Nevertheless, it is advisable for each exchange platform to have a clear vision of its target audience. Researchers, business

persons and the general public seek different information with various degrees of specialisation. These instruments should be initiated, and most of all administered, by Africans so that they reflect African concerns.

But it is just as important to conduct an intellectual-property policy in favour of open science, by excluding life and knowledge from the scope of patents, and by transitioning scientific journals into publications based on open access, creative commons. Note that the shamans of 20 Indian tribes in Brazil, meeting in early December 2002 in São Luis, wrote very officially to the World Intellectual Property Organisation with the backing of the Brazilian government to protest against the fact that their traditional knowledge – often related to the sacred domain – could be patented (Barthélémy, 2002).

However, according to A. Ouédraogo (UNECA, 2007: 5) of the International Labour Organisation (ILO), the knowledge economy is skills- and gender-biased and tends to generate income inequalities and unbalanced access to opportunities. Techno-science is indeed still male-dominated, unlike the humanities and human sciences.

KNOWLEDGE PRIVATISATION AND COMPETITION

On the basis of democratising information – which, in itself, is legitimate – a more questionable approach is often made official: That of systematic competition with the other economic powers (Boudet, 2008). The knowledge economy thus tends to format public opinion and institutions according to the dominant criteria of growth and instant profitability; this occurs to the detriment of the services which must nevertheless continue to be dispensed by science, art and culture in order to maintain an acceptable level of social cohesion both at school and in society (Richez *et al.*, 2009). According to Alain Trautmann (2009), the leader of the “Sauvons la recherche” (“Save research”) movement, which expresses the concerns of French researchers and plenty of their fellow citizens, this knowledge economy, by systematically linking research and innovation, is increasingly tending to constrict research activity. The knowledge economy promotes useful research with a technological purpose, which eliminates the human and social sciences. The training of the individual and the citizen, and the ability of societies to revitalise and redefine themselves are thus severely unbalanced, benefiting growth with no prospect of the sustainable development of civilisation (Boudet, 2008).

Amable and Askenazy (2003) thus warn against the normative aspect associated with the knowledge economy: A reform of institutions and organisational modes accompanying a new age of capitalism that is supposed to be characterised by intensified competition and flexibility. Some of

these elements are a myth; others are orienting societies towards a single model of capitalism under cover of technological determinism or of the need for modernity.

Knowledge is henceforth understood to be marketable only, a privatised factor or private growth; an object of trade: Instructive in this respect is the definition of the digital economy (“e-finance, e-transactions, e-commerce, e-trade and e-content, e-legislation”) in UNECA (2009: 3). The primary objective is the commercialisation of science, knowledge and life, followed by researchers being urged to be “competitive”. The socio-cultural and institutional environment is thus becoming ever less conducive to basic or societal research and to knowledge that is hard to commercialise.

Trade, communication and business methods are now used to manage, and even produce, knowledge. This was epitomised by the holding of an “idea factory” at the UN “Science with Africa” conference in March 2008 in Addis Ababa: A sort of multi-session brainstorm, during which hundreds of participants launched thousands of ideas, from which a committee of unknown consultants extracted 20. This big bar-room discussion ignored the fact that the difficult thing is not to produce ideas or even to select the best ones, but to produce original and potentially productive ideas. It will subsequently be necessary to convince the community that they are good ideas, because the most original and doubtless most productive ideas are precisely the most vulnerable to all sorts of criticism and which meet with the most resistance. Original ideas are vulnerable because new: They are not yet well developed enough to be understood. It is therefore hard to defend them, because the arguments in their favour have not been fully constructed. This is why original ideas are often the most difficult to win approval for.

In addition, who has the power and is supposed to choose from among the ideas put forward, to decide which are admissible and which are not? This is a strategic activity for the African society in question. It requires highly-cultured people with very open minds. The legitimacy of the people tasked with this job is essential for the selected new ideas to gain social recognition and thus be embraced. In addition, Leach *et al.* (2005) argue that many non-western views of knowledge, as seen in research in development studies, still do not fit with the prevailing view of “expert knowledge” in the west and thus may not be considered legitimate. And even when scientists reach out for local knowledge, they may lack important skills needed for success.

This method, which occupied the participants for a good part of the conference, is in favour of banality and marketing, far from difficult intellectual production and its scientific rigour, which are essential for “improving capabilities”.

There is a need to develop appropriate policy in Africa to design and apply knowledge based services for marginal people (Stigter, 2006).

RESEARCH SYSTEM AND ITS CONNECTION WITH DEVELOPMENT

At the same conference, with the notable exception of several excellent papers – in particular by the president of the Academy of Sciences for the Developing World (TWAS), the representative of UNESCO, and a member of the European Research Foundation (ESF) – there was no analysis of the social and economic conditions of research, of scientific activity, or of the transfer of knowledge and know-how: Analysis of scientific staff and of the conditions in which they work; of the fields they cover; of the conditions of success. The human and social sciences were curiously absent, as if their development were only a matter of techniques and not, firstly, of human resource.

We feel it is essential to understand the conditions of scientific production and the environment that promotes it, for the three types of research presented above – basic research, experimental development, and societal research – while investigating in depth the relationships between research, knowledge and development. Development cannot be a blind process or one led in accordance with a simplistic ideology that matches the standards of the current developed countries. The exclusive focus on companies implies that a country's development derives quasi-exclusively from the development of private-sector companies. This forgets the equally fundamental role of public services (water, electricity, transport, health, culture, education, etc.), without which solid development is not possible.

The contribution of all scientific activities to Africa's development should be studied. In particular, it would be advisable not to focus on specific aspects to the detriment of a holistic, balanced view. For example, questions must be asked about the role and boundaries of ICTs and of the geosciences in research, technological innovation, and development. This analysis cannot be done only by the professionals and operators in these domains, who are both the judges and to be judged.

Ultimately, a society cannot revitalise without analysing its actions (or inaction), its experiences, and the conditions of its past failures and successes. By this we mean a deep and rigorous analysis, and not a sub-ideology of marketing: Here, human and social sciences research has a key role to play. In activities to do with information, science and technology, great importance should be given to the human and social sciences and not just to engineering sciences; and, indeed, to life sciences. Only human and social sciences can address questions such as: What are the

decision-making processes? How is a transport system organised? What are the different economic systems in farming? What are the cultural barriers to innovation? Which cultural resources promote innovation and development? Which elements of traditional knowledge and know-how are liable to be factors of development? In development, what are the respective roles of the market, public services, and the informal sector? What role do international relations play in development? Which elements of governance accelerate or impede development?

PRODUCING KNOWLEDGE LOCALLY

The analysis of conditions of knowledge and know-how production obviously complements production itself. But political decision-makers need fast answers to their questions (projects, plans, policies, etc.). When national research has not been developed, as is the case in many countries in the South, there is no training through research or, consequently, emergence of local skills, including in research firms. Neither national research nor consultants in the South can therefore provide a general response to these questions.

The decision-makers will then use consultants or researchers from developed countries. Those unversed in local realities, and lacking the time or resources to become properly acquainted therewith, propose solutions that are formally good but with content based on their knowledge and culture, in a kind of copy-and-paste approach. Most often, these solutions are inadequate in substance because their execution is problematic owing to an unsuitable socio-cultural environment. Through regulatory or advertising pressure, they can provide an acceptable short-term response, but it will not be sustainable.

The response to this is definitely investment in local research, and firstly by more highly valuing local researchers and giving them recognition.

The objective of research, however, must not be responding to the questions of political decision-makers. The link is more complex: Research activity creates knowledge and know-how, promotes local skills, and thus increases the scientific skills of society, which enables local consultants to respond directly and properly to decision-makers' requests. An essential prerequisite for research is independence.

The research independence allows detachment from official data and from local knowledge and know-how, which, as far as possible, must be questioned before being validated. Independence is primarily necessary because research is not guided by a policy of narrow and short-term objectives. Electricity and the electric bulb were not discovered while improving the candle. The results of research are generally unexpected. This is true of basic

research, but also to a great degree for societal research, which is far more productive than the simple question that drove it. Only experimental development is wholly guided by a precise objective, using existing knowledge.

Collaborative research between researchers and universities is the most productive, and though it is promoted in policy messages, it is made very difficult by research conditions. Real backing should be given to researcher networks by eliminating obstacles in terms of regulation, management, finance and personal careers so that collaborative research is genuinely encouraged, particularly among the countries of the South themselves. Researchers and sector professionals must therefore initiate and take part in specialist networks, which for a relatively small cost set up excellent ways of optimising research resources, notably through coordination, efficient exchange and training schemes, and the dissemination of knowledge and findings. This can be networks at every level, from regional to international. The pooling of knowledge, tools, methods and solutions is necessary; though it must always be adapted to the context of the considered country or region.

PROGRAMME TO STRENGTHEN RESEARCH-DEVELOPING CAPABILITIES IN AFRICA

Africa needs the international community's support to strengthen its capability to develop its research. The United Nations, convinced that Africa needs medium- and long-term scientific research for its development, can develop a support programme in synergy with the other ongoing programmes, to reinforce the development of research in Africa. The United Nations University, UNESCO, the UNDP and other UN organisations can make an effective contribution to an integrated programme by leveraging their experience in these countries, in order to support the development of research in the various disciplines of interest by country and by region: Intangible support for research (excluding facilities); facilitation of exchanges; joint projects; and the dissemination of skills and findings. The programme could revolve around the following:

A. STRENGTHEN THE SELF-CONFIDENCE OF AFRICAN RESEARCHERS

- Improve institutional recognition of African researchers (pay, consideration), which would help keep brains in Africa;
- Promote researchers' intellectual fulfilment by trusting their creative abilities, which would promote the emergence of African thinkers who would drive Africa upwards;

- Promote African researchers' mobility, so that they can leave and then be able to come back;
- Encourage African expatriates to take part in the development of research in their country of origin;
- Host foreign students, especially from the North, in universities and research teams;
- Set up research projects on a North-South cooperation basis;
- Fund the hosting of North researchers for short assignments in African research teams;
- Encourage the authoring in Africa of dissertations on topics of African interest, co-directed by parties from North and South;
- Publish articles co-authored by researchers from North and South; and
- Summarise and publicise successful experiments conducted in Africa.

B. BUILD AN AFRICAN RESEARCH COMMUNITY

In order to promote knowledge and know-how transfer between southern countries:

- Promote interactions and networking with African researchers by holding conferences and seminars in Africa and by giving logistical support to participants;
- Encourage the creation of bi- or multi-lateral, mono- or multi-disciplinary African research teams, by promoting the set-up of research cooperation projects;
- Facilitate the physical mobility of researchers in Africa by lifting regulatory and logistical barriers, especially for transport; and
- Train researchers and students in research tools (software, hardware) and primarily in the specific methods of research: Invest in people rather than equipment.

C. COVER THE DIFFERENT FORMS OF RESEARCH

- Provide equal support to the different forms of research: Basic research, experimental development, societal research;
- Draw on the knowledge and know-how transmission needs of the various tiers of African society in order to supply societal research;
- Take a holistic, mid- to long-term approach to research; and
- Promote multi-disciplinary research (engineering sciences, life sciences, human and social sciences).

D. STRENGTHEN RESEARCH-MANAGEMENT INSTITUTIONS

- Improve the capabilities of research-management staff by training them in this specific activity, using workshops and seminars on research.

E. DISSEMINATE KNOWLEDGE

- Encourage and facilitate the publication and dissemination of the findings of research done in Africa; and
- Support and encourage the development of online African science journals on an open-access basis.

This detailed proposal needs to be discussed and developed further. It could draw inspiration from the experience of the COST initiative.² Since 1971, this inter-governmental initiative has had the purpose to increase cooperation and interaction between researchers in nine scientific domains that cover most of the field. COST is organised by single cooperation “actions” on a given topic, with a limited number of researchers from at least five countries, for a period of three to four years. For example, COST funds participation in action-coordination meetings, inter-laboratory researcher exchanges lasting one to six months, training schools, seminars and, lastly, the dissemination of findings in the form of dedicated reports, conferences and websites. The initiative is open to non-European countries and particularly to Mediterranean-basin countries. Support from COST or another European source can certainly be envisaged for an African capability-strengthening programme.

The first stage could be to set up a pilot project of cooperation in a specific domain.

CONCLUSION

It is hard to manage the scientific activities efficiently with the aim of development when their characteristics are not known. One must define the outlines and activities of research and innovation: What are their objectives, methods and roles? How are they different and complementary? In what conditions are they conducted? Who are the stakeholders and participants?

We argue that apart from the three types of conventionally recognised research – basic research, applied research and experimental development – we have to add the targeted societal research for decision-making, which introduces a major stakeholder, the society as a whole.

The discussion of these different research types indicates that the relevant contrast appears to be less between basic research and experimental development than between commercial or market-driven research and public-service research not mediated by the market. The open knowledge plays here a fundamental role in the evolution of the societies and in their development.

The concept or ideology of the knowledge economy nevertheless favours instant profitability and constricts research activity, by promoting useful research with a technological purpose, which makes very marginal basic research, societal research, human and social sciences, and all what could allow the citizens as the societies to revitalise and redefine themselves. The exclusive focus on companies implies that a country's development derives quasi-exclusively from the development of private-sector companies. This forgets the equally fundamental role of public services, without which solid development is not possible (including technological development).

The knowledge economy appears thus opposed to knowledge creation. However, basic research that creates new knowledge in exact or social sciences is absolutely necessary to deal with and respond to the numerous challenges and problems faced by each society regardless of whether the society is poor or rich.

NOTES

- 1 Committee on Development Information, Science and Technology of UNECA, Addis Ababa, 28 April – 1 May, 2009. Available at: www.uneca.org/codist/codist1.asp.
- 2 European Cooperation in Science and Technology. Available at: www.cost.esf.org.

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Ghana's Innovation System

What's Wrong With It, and Why

Jo Lorentzen

SUMMARY

Science, technology, and innovation (STI) are expected to play a key role in lifting Ghana to middle-income status by 2020. Ghana is not alone in wanting to promote STI as a means to socio-economic development; governments throughout Africa have been making political commitments in support of the knowledge economy. The paper provides a micro-assessment of the Ghanaian national innovation system (NIS) and in particular of the role of the public research institutes and the three oldest and largest universities. It addresses the adequacy of public funding for the system along with its scientific and technological output and finds both below par. Reasons for underperformance lie further in the management of human resources, underdeveloped and badly understood institutions, widespread coordination failures, a lack of reflexivity, and a general absence of effective linkages between the various elements of the system. The paper also points to success stories that illustrate the untapped potential of the NIS and suggests how the system could be improved.

INTRODUCTION

On the back of strong economic growth throughout much of the past decade, Ghana aims to graduate from low- to lower-middle income status by 2020.¹ This requires the application of science, technology, and innovation (STI) to those activities that have the highest growth potential, and ideally to the economy at large. Linking knowledge and productive activities must prominently involve the research capacity embodied in Ghana's universities and public research institutes. This paper provides an assessment of the effectiveness with which Ghana's NIS does that.

The overarching question is whether the system is geared such that knowledge production can advance Ghana's developmental agenda. To this end the paper investigates funding, performance, human resource development (HRD), institutions such as the intellectual property rights (IPR) regime and peer review, and selected linkages within the system. If NIS describes the dynamic co-evolution of knowledge, innovations, organisations, and institutions, it is important to understand which part of the system is dysfunctional or inert, thus holding back overall system performance (cf. Soete *et al.*, 2009).

The paper proceeds as follows. It first describes the past and recent context of the role of STI in Africa and in Ghana more specifically. Then it presents data and methodology. The subsequent sections relate the resourcing of the system to its performance, and analyse human resource development, institutions, coordination, and linkages. The final section concludes with recommendations for policy.

CONTEXT

Throughout Africa a policy environment conducive to fostering the knowledge economy is emerging (African Development Bank, 2007; African Ministerial Committee on Science and Technology III, 2007). Good (policy) intentions are not in short supply. The question is how much difference this will make in the future. For the time being, no matter which innovation, education, or training indicators one consults, Africa still scores way below the world average in everything that matters.²

Recent assessments of STI policies in Africa do not mince their words. In the Southern African Development Community, science policies are “vacuous (and merely symbolic) documents with little or no effect, mainly because of a lack of resources and (in some cases) lack of will to give expression to the goals and objectives of these documents” (Southern African Regional Universities Association, 2008: 7, see also Mouton and Waast, 2008). This is not a new finding; investments in agricultural research on a per scientist basis in Africa declined from the late 1970s, with considerable effects on the efficiency and effectiveness of the agricultural research system (Pardey *et al.*, 1995). Similarly, UNCTAD (2007, Chap.2) concludes that the new emphasis on growth is not matched by attention to technological change as an important source of that growth, partly due to the fragmentation of science and technology (S&T) infrastructure in the 1990s.

Past STI policies and capabilities in Ghana attract their fair share of criticism (Lall and Pietrobelli, 2002, Pietrobelli, 2001, UNCTAD, 2003). Research on the evolution of NIS suggests that the number of and channels

for interaction among scientific infrastructure, technological production, and economic growth change in relation to the level of economic development (Bernardes and Albuquerque, 2003, see also Chaves and Moro, 2007). Thus, at low levels countries have so little scientific output that no technological production results. Such low levels must be seen merely as a stepping stone to successively higher levels of investment simply because “a little bit of science” is unlikely to generate even only “a little bit of technology”. At medium levels, interactions and feedbacks between the two start to materialise. At high levels, all connections are operative. An important conclusion of this work is that there are thresholds between these various levels which move over time. Since the technological achievements of the world continuously progress, the national efforts of developing countries with ambitious STI agendas must be dynamic as well for catch up to result.

These insights underline the importance of STI in the Ghanaian context. However, to date the role that STI might play in Ghana's development has received relatively short shrift (Bogetić *et al.*, 2007).³ In the terminology of Ghanaian planners, the country is ready to move to the economics of accelerated growth (National Development Planning Commission, 2005).⁴ This implies diversification from the cocoa-gold-timber structure towards industrialisation, technology, and high productivity. The strategy is led by agriculture, which needs to be weaned off its traditional over-reliance on cocoa to make space for cereals and other cash crops for export. Modernising agriculture is key both because the majority of the population lives off it and because such a process will open up opportunities to change the relationship between agriculture and industry. The planners allocate important responsibilities in the implementation of this strategy to the Council for Scientific and Industrial Research (CSIR) (*ibid*).

In summary, there is awareness in Ghana that STI policies are essential to achieve accelerated growth and join the global knowledge economy. By implication, it is clear that the country's knowledge infrastructure, notably the universities and public research institutes, has an important role to play in Ghana's development. Assessing the recent performance of this knowledge infrastructure is thus a first step toward designing effective STI policies.

METHODOLOGY AND DATA

Understanding the extent to which knowledge production in Ghana's NIS advances the country's developmental agenda requires an assessment both of the inputs into the system and the efficiency with which actors in the system convert such inputs into performance. Evidently, problems can

arise because essential resources are lacking or because available resources are not well used, or both. Lack of investment has affected technological innovation in the developing world and in Africa in particular for a long time. This has led to the appointment of inferior scientists that accept low salaries in the public research sector and to frustration due to inadequate working conditions in the universities (Crane, 1977: 380). Especially in agricultural research, there has been a high level of incongruence between the growth in the number and the calibre of research staff and declining research expenditures which already in the 1990s was judged unsustainable (Pardey *et al.*, 1995).

Innovative behaviour can of course also result precisely because conditions for STI in low-income countries are rarely if ever ideal: Infrastructure is out of date, essential equipment is unavailable, people with the requisite skills are scarce, funding is insufficient, and institutional support is absent or ineffective. In this sense, cognition and problem solving have to adapt to scarcity conditions that are a much more binding constraint than in the developed world (Srinivas and Sutz, 2008).

The paper therefore discusses inputs and outputs and how they relate to one another. This is done on the basis of statistical evidence in conjunction with interviews with researchers, academics, and managers in a number of Ghana's research institutes and universities. Specifically, it covers the Council of Scientific and Industrial Research (CSIR), and in particular four of its specialised institutes, namely the Crop Research Institute (CRI), the Food Research Institute (FRI), the Institute of Industrial Research (IIR), and the Oil Palm Research Institute (OPRI). In addition, it covers two institutes that fall under the Ministry of Health and the Cocoa Board, respectively, namely the Centre for Scientific Research into Plant Medicine (CSRPM) and the Cocoa Research Institute of Ghana (CRIG). The three universities included are University of Ghana (UoG), Kwame Nkrumah University of Science and Technology (KNUST), and University of Cape Coast (UCC). The sample thus includes the country's oldest and largest universities, plus research institutes whose remit has direct relevance for agricultural productivity, food security, health, and industrial diversification. Although they are only a subset of Ghana's NIS, due to their relevance their performance sheds light on the system as a whole.

Some caveats about data availability and quality are in order. First, Ghana's research system is in general very poorly documented. Much key information is either not available at all or only with considerable difficulty. For example, in July 2008 the most recent annual reports of the CSIR's 13 institutes available in the CSIR library were up to five years out of date, and for selected institutes not available at all. Web documentation was even more incomplete and occasionally contradicted information published in hard copy.

Second, the quality of this documentation leaves much to be desired. For some institutes, annual reports are virtually identical from year to year and omit essential and mandated information such as publications output. By contrast, a few universities report output under “journal publications” that has neither been published nor accepted by a journal, but merely submitted, or was published in another medium.

Third, some data are intensely political and access is jealously guarded or genuinely unknown. This primarily concerns information about funding and external income, and thus important data to assess linkages with industry (for more details, see Lorentzen, 2009). Such problems preclude any attempt at statistically representative analysis. Instead, it is the combination of incomplete quantitative data, case study evidence, and extensive interviews with actors in the system that is used to assess whether micro problems identified cumulatively translate into systemic macro weaknesses.

NATIONAL INNOVATION SYSTEM IN GHANA

LITTLE BANG FOR SMALL BUCK: FUNDING OF GHANA'S RESEARCH SYSTEM

In 2008 the Ghanaian budget devoted just over one per cent to R&D.⁵ Spending on tertiary education which also includes research activity, amounted to another 3.1 per cent. A large majority of these funds was spent on salaries. Importantly, core-to-support staff ratios are very low and range from one to ten at the CSIR to one to three at the country's premier S&T university. Administration costs accounted for 10.7 per cent at the universities and almost twice that much at the CSIR. Hence, in both cases staff and administrative expenses made up more than 90 per cent of the budget, leaving between four (CSIR) and eight (universities) per cent for operational and capital expenses related to research. Capital expenses tended to be even lower than operational expenses. In sum, research received short shrift both absolutely and relatively.

Based on this and related data (Lorentzen, 2009), the CSIR is a top-heavy organisation that employs its staff without giving them the means to do research. Apart from some building rehabilitation, much of which benefits its headquarters, the CSIR has been running down its assets. In fact, annual reports of the 13 individual institutes constituting the CSIR noted the challenges of inadequate research funding, especially to equip laboratories and workshops (IIR 2004, ISTI, 2006), inadequate and late release of funds from the government (FORIG, 2005, WRI, 2004), and unsatisfactory resources for infrastructure and farm machinery (SARI, 2003), to name just

a few. Researchers interviewed for this study complained about outdated or badly maintained and broken equipment in their laboratories.

The high share of salary costs in the research system does not imply that researchers are adequately paid. While university salaries do guarantee incomes on which people can survive, the majority of CSIR researchers moonlight because their compensations do not sustain themselves and their families. Yet although universities are relatively better off, they also count poor remuneration and poor service condition for staff, alongside inadequate funding of academic programmes, and run down infrastructure among their major weaknesses (KNUST, 2005a, Report of the Visitation Panel to the University of Ghana, 2007, UCC, 2003). For example, at Kwame Nkrumah University of Science and Technology, laboratories set up in the 1960s largely host the original equipment and facilities which have not been upgraded since (KNUST, 2005b).

To recapitulate, the inputs to Ghana's research system leave much to be desired. What about the outputs and the outcomes?

Outputs and outcomes

Table 1 shows basic indicators of Ghana's largest universities. Graduate enrolment is relatively low. According to the World Bank's Knowledge for Development database, the national science and engineering enrolment ratio in 2007 was 26 per cent.⁶ In 2007, all universities graduated fewer than one per cent of their students with a PhD in all science and engineering subjects, meaning that they contributed barely a handful of highly-trained junior scientists or engineers to the country in a given year, including for the replenishment of their own faculty. In 2005, the whole country published 81 science and engineering articles, most with foreign co-authors (*ibid*). In 2006 and 2007, the ratio of academics to articles published in a peer-reviewed journal ranged from four to seven in the three universities. Many papers were published in in-house or other Ghana-based journals. About every third paper was published in a journal recognised by the Institute for Scientific Information (ISI). The quantity of publication output does not sit easily with claims to academic excellence. For example, in its strategic plan, KNUST's College of Science refers to the quality of academic staff as one of its strengths. "Most of them have attained high reputation in their fields of study and rank among some of the best scientists in the World. Quality research findings by faculty members are published in reputable journals..." (KNUST, n.d., 5).

The academics tend to blame a huge teaching load for their low research output. In fact, enrolments in all universities have doubled or tripled over the ten years to 2007 in order to generate income, reaching 17,000 at UCC

Table 1 Ghana's Universities: Basic Indicators

	University of Ghana (UoG)	University of Cape Coast (UCC)	Kwame Nkrumah University of Science and Technology (KNUST)
Year established	1948	1962	1952
Enrolment			
Total	29 754	16 806	23 866
Male/female ratio	1.5	2.1	2.5
Postgraduate	1 816	394	1 597
Undergraduate	26 154	16 140	22 269
Sub-degrees	1 784	272	./.
Graduate enrolment, %	6.1	2.3	6.7
International students	1 142	./.	736
Staff			
Teaching and research	865	398	778
Academic staff with PhDs, %	46.8	./.	39.9
Admin. and professional	3 909	3 032	2 580
Ratio academic/support staff	0.2	0.1	0.3
Ratio academic staff/students	.03	.02	.03
S&T teaching			
Science students, %	19.9	26.0	48.8
S&T graduates, 2007, %	8.5	23.6	63.5
S&T PhD graduates, 2007, %	0.16	0.0	0.08
Journal publications			
Listed on university website for 2007	1	0	12
Listed in Annual Report	230	50	165
Output per capita	0.27	0.13	0.21
ISI 2006	73	15	54
Ratio ISI/other journals	0.32	0.30	0.33
<i>Note:</i> Science students are those enrolled in the natural sciences. Publications listed in the Annual Report refer to 2006 for UoG and UCC, and to 2007 for KNUST. Publications output per capita is derived by dividing the number of articles through the number of teaching staff.			

Sources: ISI Web of Knowledge (2006); KNUST (2008a,b); UCC (2007a,b); (UoG 2007a,b); University Websites.

and 30,000 at UoG. Since this happened without a concomitant increase in the number of teaching staff, student/faculty ratios obviously rose, thus making the teaching load heavier, so that each faculty member is responsible for between 30 to more than 40 students.

Table 2 provides similar information about the CSIR and other public research institutes. Measured in publication output in refereed journals, the CSIR's research productivity is even lower than that of the three large universities. In 2005, six of its 13 institutes did not publish any papers at all.⁷ The remaining seven accounted for a total of 31 publications, making for a CSIR-wide per capita publication output ratio of 0.08.

Although evidently very low, this is not seen as a problem either at the corporate level or by the individual institutes, none of which identified this as a challenge in their annual reports. In its Strategic Considerations 2005-2009, the CSIR underlined its ambition to "extend our impact beyond our walls through **Scientific Publications** that will showcase our achievements and our role as thought leaders of the African scientific community" (CSIR n.d., 8; emphasis in original). Towards the end of the past decade, the CSIR was nowhere near this aim.

None of this research gets turned into globally recognised technologies. The United States Patent and Trade Mark Office registered ten patents to Ghanaian inventors between 1977 and 2008. Four of these were granted to academics associated with UoG, three to academics associated with KNUST. It is likely that these patents represented team efforts headed by multinational firms, with the Ghanaian inventor one of several team members. Thus the assignee was in every case a foreign entity in the US or Europe, meaning that no intellectual property from this patenting activity resides in Ghana itself.

Individual institutes suffer noticeably from the lack of resources. For example in the health field, the Centre for Scientific Research into Plant Medicine (CSRPM) has no lab facilities to isolate active ingredients or marker compounds. The focus is therefore on qualitative work and preclinical evaluations. Compounds must be sent abroad for testing. Hence there is as yet no proper drugmaking capability. In the absence of linkages to established organisations and thus international exposure, collaborations with pharma or biotech companies, and scientists with expertise in molecular biology and nanotechnology, there has been no local presence in third generation biotechnology. Not surprisingly, biotechnology and pharmaceuticals exports based on Ghana's abundant biological diversity have not materialised.

Similarly, the Crop Research Institute (CRI) does not have an irrigation system to allow it to run two or three planting cycles per year. It relies entirely on precipitation. This affects its ability to earn external income. Its deficient lab facilities also compromise its work. Its biofortification research needs testing that can only be done abroad. And since there are centres, including in Africa, that are much better equipped, the big international crop research contracts tend to go there, while CRI has to contend itself with lesser work.

In essence the whole system is on life support. For the most part things work badly, and without external and international partners they would not work at all. In the long term, unless Ghana offers specific knowledge competences, the country will not be able to run the system on a shoe-string the way it has been doing, even if only to forestall total shutdown. Despite the lip service it pays to S&T, the government seems to regard the research system primarily as a cost item. This is a partial explanation why some parts of the system are reluctant to divulge information on external income. For there have been instances when government “rewarded” an increase in competitively sourced funding through a decrease in its subvention. This is the exact opposite of the idea of co-funding which is the norm in much global research funding. But when external funds become a substitute for government contributions to the budget, the resulting trade-off pretty much destroys whatever incentive there may have been to raise external funds.

In sum, Ghana's research system is underfunded and it does not perform to the standard it set itself. The two are obviously related; performance relies on resources and, in their absence, can only be poor.

HUMAN RESOURCE DEVELOPMENT

Any research system can only be as good as the human capital on which it is based. Harnessing that capital is therefore of utmost importance. This refers to the competence of the (scientific) workforce, its motivation to excel, and the incentives the system provides to encourage such dedication.

Human resource management at the CSIR is regulated in its Conditions of Service (CSIR 1996a, b). Promotions to higher levels of seniority depend on minimum requirements such as academic qualifications, a certain number of publications (including technical reports), and a minimum number of years spent at the respective lower level. This last condition may be waived in exceptional circumstances. Its logic is questionable. Star scientists who fulfill all conditions for promotion except the time factor are unlikely to perceive such a system as truly meritocratic. Also, a staff member who in Year 1 of her tenure at a given level publishes the three to five articles required for promotion to the next level, has no incentive to continue to publish in Years 2 to 5 in that her research productivity does not really affect her career progression anyway.

In its strategic document covering 2005–2009, the CSIR (n.d.) acknowledges the need for highly motivated staff and world-class skills and competencies to meet the needs of its target markets. It announces that it would by 2005 review and enhance incentive packages for staff and revise promotion criteria to encourage accelerated promotion at all levels. In 2008, this

had not yet happened. For example, young scientists entering the system might spend years in the library and never much see a lab from the inside, let alone conduct experiments. This obviously affects their competence and negatively impacts their ability to assemble data to live up to their publication targets. The problem they share with senior staff is that laboratory equipment is often so outdated that journals reject submitted papers because of experimental methodologies that are regarded as outmoded by the profession. These difficulties reflect a larger problem with incentive alignment for human capital in the system.

Although the CSIR Secretariat and the individual research institutes have commercialisation officers, they do not have dedicated positions for research project acquisition. Since this is upstream from commercialisation, it does not support technology development. Of course, highly motivated individuals can still apply for international research funding. But they are competing against peers elsewhere with much better developed support systems. In addition, not all institutes practice an award system for staff who bring in large international research contracts, even though this affects their core activity.

The Ghanaian research system affords staff little international exposure. Since research is increasingly performed in large, international networks, this is a problem because it hinders integration into such consortia. The fact that the research system supports its scientists and academics neither directly (through active marketing, systematic intelligence on tender opportunities and the like) nor indirectly (for example, through informative and functional websites), makes the situation worse.

This dim view of HRD in the research institutes is also borne out by strategic reflections undertaken in the universities. The Visitation Panel that reviewed UoG in 2007 made a point of recommending strengthening the faculty through systematic mentorship of young lecturers, including induction and orientation programmes for new appointments (Report of the Visitation Panel to the University of Ghana, 2007). It also recommended introducing a two-track salary system where research competence and output would determine differential remuneration in order to provide incentives for highly productive academics to commit to a university career. UoG largely accepted the criticism and recommendations emanating from the report (Council of the University of Ghana, 2008). Since it had declared as early as 1994 that the development, utilisation, and retention of a high-calibre faculty was an essential stepping stone on the way to achieving its mission (UoG, 1994), it is not correct that solutions to HRD problems elude the universities; rather it seems to be an unwillingness or an inability to implement them that is the problem (for similar observations regarding the other two large universities, see KNUST, 2005a, b, UCC, 2003).

Table 2 Selected Indicators – Research Institutes

	ARI	BRI	CRI	FRI	FORIG	IIR	ISTI	OPRI	PGRRI	SARI	SRI	STEPRI	WRI	CSIR	CSRPM	CRIG
Staff	295	211	883	170	286	135	79	440	127	535	372	31	249	3 813	180	1 200
of which: research	27	27	83	34	38	18	13	23	9	35	26	9	56	398	22	47
with PhDs	9	0	24	12	14	4	1	2	2	8	0	3	20	99	6	17
Journal publications in 2005	2	0	7	0	4	0	3	2	0	0	10	0	3	31	10	8
per capita	0.07	0	0.08	0	0.11	0.00	0.23	0.09	0	0.00	0.38	0	0.05	0.08	0.45	0.17
ISI (2006)	2	0	2	2	3	0	0	0	0	0	0	0	3	9	2	2

Note: CRIG publications are for 2000. The figure for CSIR ISI publications might partially overlap with those of the institutes; it is not the total for the entire organisation. ARI = Animal Research Institute, BRI = Building and Road Research Institute, CRI = Crop Research Institute, FRI = Food Research Institute, FORIG = Forestry Research Institute of Ghana, IIR = Institute of Industrial Research, ISTI = Institute for Scientific and Technological Information, OPRI = Oil Palm Research Institute, PGRRI = Plant Genetic Resources Research Institute, SARI = Savanna Agriculture Research Institute, SRI = Soil Research Institute, STEPRI = Science and Technology Policy Research Institute, WRI = Water Research Institute, CSIR = Council for Scientific and Industrial Research, CSRPM = Centre for Scientific Research into Plant Medicine, CRIG = Cocoa Research Institute of Ghana.

Source: CRIG (2000), CSIR (2006) for publications; CSIR website for staff complement; CSRPM (n.d. a, b) (SIWeb of Knowledge (2006).

On a positive note, the introduction of annual book and research allowances has somewhat improved working conditions.

In sum, the analyses embedded in the various strategic plans reviewed here suggest that human resource management and development have either not been pursued systematically at all or have become a mere bureaucratic routine that has not adapted to changed circumstances. The result is that the research system's most important capital, people, is shortchanged. Inputs from scientists interviewed for this study, independent of seniority, bear this out. This is an enormous problem because highly trained knowledge workers will continue to opt for careers in science and academia – which are less well remunerated than positions in industry – only if their motivation and ambition is matched by organisational practices and policies that are receptive to and supportive of their expectations.

INTELLECTUAL PROPERTY RIGHTS (IPRS) IN THE RESEARCH SYSTEM

The impact of IPRs on developing countries, especially subsequent to the introduction of binding worldwide regulation under the auspices of the World Trade Organisation in the mid-1990s, is controversial. In theory, more IPR protection should lead to more innovation in the long run although this definitely imposes costs on the laggards in the short run. But there are differences among more and less advanced developing countries, and how such costs and benefits exactly manifest themselves is essentially an empirical question. Stronger IPRs are generally associated with a rise in knowledge flows to affiliates of multinational firms and in inward foreign direct investment to middle-income and large developing countries, but not to poor countries (Comin and Hobijn, 2004). Patents do not seem to influence the incentive to innovate in developing countries themselves, but other forms of IPR such as utility models do.⁸ In other words, in countries with weaker R&D capacity, what matters for innovation, technological diffusion and growth is the protection of minor, incremental innovations; type rather than strength of protection is important (Kim *et al.*, 2008).

The purpose of this section is not to discuss benefits and costs of IPRs in the case of Ghana, although this is of course an important issue. The point is rather to relate intellectual property emanating from the country's research system to its emerging IPR framework (Industrial Designs Act, 2003, Patent Regulations, 1996, Trade Marks Act, 2004). This matters because the existence of a legal framework does not preclude the fact that innovations are insufficiently protected. Reasons for such a disjuncture can be manifold. In Chile for example, particularly in biomedical research, indigenously developed ideas ended up being owned and commercialised by US companies simply because the country's researchers and institutions

are steeped in a non-patenting culture (Krauskopf *et al.*, 2007). In addition, the tension between systems designed to protect codified knowledge and attempts to regulate access to and exploitation of traditional knowledge is not well resolved (e.g. Augusto, 2002).

These last observations are very relevant to Ghana, at three levels at least. First, individual researchers and academics are rarely familiar with IPR legislation. They often do not appreciate what actually constitutes a “novelty” or why it might make sense to protect it. They also suspect that registering a patent might be cumbersome and costly, even if this is not based on direct experience. Some believe that scientists are prevented from registering patents as private persons. Also, patents do not figure prominently in the rules governing promotion (see Shemdoe *et al.*, 2010, for a similar perspective on Tanzania). Second, neither universities nor research institutes have central frameworks in place that would regulate how intellectual property is to be handled, how it is disseminated or transferred, who would be responsible for the cost of servicing patents, or how possible proceeds from its exploitation are to be shared between the inventor and the assignee. Third, the government as a funder of public research in the country has not made intellectual property rights in whatever form an explicit yardstick against which it measures the performance of the system. In sum, there are no incentives inherent in the system that would encourage anyone to take the national or the global system of IPR protection seriously.

The absence of institutional IPR management systems leads to a situation where nobody knows whether there is any intellectual property worth protecting in the country, how best to do it, and what degree of locally developed ideas potentially leave the country to be exploited by someone who had nothing to do with their development in the first place. The safeguarding of indigenous knowledge is a particularly sensitive issue. Not only are there instances of biopiracy in the developing world. More importantly, in the absence of a framework that ensures a fair sharing of the gains from the exploitation of traditional knowledge, the poor are most in danger of being adversely affected in an area where control over assets might actually help them to achieve sustainable livelihoods (Cottier and Panizzon, 2004, Srinivasan, 2003).

COORDINATION FAILURES AND MISSING LINKAGES

The research institutes and universities are only one part of Ghana's NIS. Hence when assessing their performance it is important to distinguish between them and the system at large. There are instances where relevant knowledge has been produced but left unutilised, not because of something the universities or institutes have or have not done, but because of what

Gerschenkron (1962) terms “missing prerequisites”. A few examples illustrate this.

Scientists at the Institute of Industrial Research (IIR) have developed a cassava processing plant. In contrast to traditional practice, it utilises all inputs from the root, including peels. It produces a range of inputs both for the food processing industry and for industrial purposes. After completion, it requires some form of funding for rural communities to be able to afford to purchase and use it. Since its operation depends on professional management, it also requires the setting up of a structure whereby community ownership (e.g. through shares) is reconciled with the employment of a professional manager. Yet this funding has not been forthcoming. Banks are reluctant to invest in agricultural projects, and there is likewise no other public credit facility available. The absence of credit also prevents entrepreneurs from acquiring the plant. Therefore this plant now sits idle, with little prospect of generating an income stream that would ultimately justify the initial investment in the technological development.

Another example is an oil palm kernel separator developed at the Institute for Industrial Research (IIR) which is an improvement over the (dirtier, less productive, and physically very taxing on the women that do this job) clay-slurry method traditionally used. Whereas in the traditional method four women take up to two days to produce a 50kg bag of kernels, the mechanical separator manages to do the same job in just 15 minutes. The development of this technology was co-funded by the World Bank and involved a private firm which undertook the actual fabrication (Amoah and Aggey, 2003, 2006). Poor management eventually sank the project. This not only means that a potentially promising piece of technology is never put to the test, but that there is no institutional learning to ensure that such wasted opportunities do not repeat themselves in the future.

CSIR food scientists were involved in a ten-year effort to increase the quality of local rice so as to substitute imports from Asia and elsewhere. Certain areas of Ghana, especially in the North, lend themselves well to rice cultivation. However, the quality of local rice has traditionally not been high, in terms of purity and appearance. Partly this depends on inputs such as land and seeds, but post-production methods have also been a problem: Late harvests from water-logged fields that lead to cracked grains, threshing on the bare ground without a tarpaulin, etc. The cracks are difficult to avoid, which is why farmers parboil the rice. The scientists designed a vessel for parboiling that reduced water and fuel input. They also organised for farmers to receive training in good practices. However, local rice production did not ultimately go up, rice is still largely imported, and the project was therefore not a success. An important reason for failure was the cost of high-quality seed, which the farmers could not afford once international

funding supporting the project had run out, so that they faced market costs for inputs.

In a similar case, crop researchers at CRI produced a series of improved varieties of maize, cassava, and vegetables. These varieties have much higher yields than conventional varieties and are more disease tolerant. For example, maize yields can go up from 1.5t/ha to 7t/ha, and cassava from 4t/ha to 35t/ha. But farmers do not use these seeds both because of poor access to markets and because they cannot afford a minimum level of input in terms of fertilizers and pesticides. The Ministry of Food and Agriculture also does not have enough extension officers to familiarise all farmers with new developments. Once again this is a case of missing prerequisites, namely access to (micro)credit and effective technology dissemination, for rural producers.

In the Ghanaian research system, the whole does not seem to be more than the sum of its parts. As these examples show, even when the parts are working, there is not necessarily a positive outcome simply because information exchange, coordination, and monitoring within the system do not take place. This means that when there is underperformance or some kind of failure, it goes unnoticed. This translates into a lot of inefficiency and, thus, a waste of potential. It is important to assess the performance of Ghana's research system in the context of the institutional limitations that constrain key linkages in the system. It would be inappropriate to hold the CSIR or the universities alone responsible for low performance when the system itself does not provide the prerequisites that are necessary conditions for that performance to materialise.

GOVERNANCE AND REFLEXIVITY

The legal framework within which Ghana's research system operates provides for regular performance reviews for most actors in the system (e.g. CSIR Act, 1996). There is no evidence that this actually takes place. None of the institutes visited in the course of this research had been subjected to such a review. This means that neither the CSIR Secretariat nor the individual institutes are used to self-evaluations, engaging with peer reviews and the like; in short, no institute has a transparent process of accountability geared toward rectifying undesirable developments and generally improving system performance.

It is no coincidence that in the absence of such a culture of reviews the CSIR has been subjected to evaluations by outsiders. In one such review, the consultants concluded that there were "deep-seated and system wide constraints" and that "the ability to manage efficiently and optimise commercial operations is significantly curtailed by inherent bottlenecks of the

existing system” (NRI n.d., 2). They recommended paring the number of institutes from 13 to five and sizeable staff lay-offs. Instead of engaging with such recommendations, the CSIR Secretariat fudged the issues. Its own strategic considerations (CSIR, n.d.) employ fashionable management terminology without heeding the most essential tenet of any strategy process, namely allocating resources to (realistic) objectives.

As we move towards our Vision, we will secure success by focusing on: [...] using well-developed, world class skills and competencies to meet the needs of our target markets. [...] We shall be indispensable to national development through the enthusiastic and relentless pursuit of the objectives articulated in these thrusts: [...] Build first class infrastructure to support R&D activities. [...] Identify and develop funding schemes that provide state-of-the-art infrastructure to support research excellence. [Note: This was supposed to be done by 2006.] [...] By carefully selecting performance indicators, we will seek to demonstrate to ourselves and to the nation that CSIR plays an indispensable role in the nation's quest for accelerated development (ibid: 13, 16, 19, 21).

These strategic considerations embraced the period from 2005 to 2009. Hence most of the objectives listed should have been achieved by the end of this decade. But there was no evidence of world-class infrastructure, nor of funding schemes that would make such plans realistic. Worse, by *not* agreeing on performance indicators and making them public, the CSIR as a whole is not really in a position to argue a convincing value proposition.

Universities are also mandated to organise reviews on a regular basis and in different ways they heed this requirement. While it is too early to know what the eventual outcomes of this process will be, it has a better chance of realising success than the CSIR's neglect of these provisions. The point here is not so much whether the universities are on or off target. What matters is that they put a system in place that allows them to monitor their own performance and, insofar as they make this information publicly available, give external stakeholders the opportunity to judge progress as well. This increases accountability in the system (Report of the Visitation Panel of the University of Ghana, 2007, UoG, 1994, KNUST, 2005a, b, n.d., UCC, 2003).

THE SYSTEM'S POTENTIAL

This study has shown that overall the Ghanaian research system does not perform well. But this is of course an assessment of averages. There are also examples of research activities followed by technology developments that have influenced growth and development in the country, or have the

potential to do so. It is important to identify such examples both so that their lessons can be absorbed and because they might be the most realistic points for policy intervention to improve the system.

In 2005 UoG created a School of Research and Graduate Studies, which is headed by a dean and supported by a dedicated research administrator, who are tasked with developing a professional research management system. Their initial activities included a research proposal writing workshop through which they began to mentor junior or otherwise inexperienced staff in accessing international research contracts. Research support further includes the provision of a list of interested donors; more systematic scanning of tender opportunities on a regular basis is planned once the School has managed to hire dedicated research facilitators for each college.

The incentives for faculty to compete for external research funds are both direct and indirect. Some projects allow for salary top-ups. As importantly, externally funded projects allow the purchase of equipment and facilities that under other circumstances would never become available. In turn, this facilitates research whose successful pursuit ultimately decides upon promotion. What might emerge out of this are strategic research agendas that not only relate to national and international priorities but establish viable activities on the ground.

The Food Research Institute (FRI) in conjunction with the Forestry Research Institute (FORIG) has been involved in a multi-year project that has tried to absorb regularly occurring cassava surpluses by expanding markets for the root (C:AVA 2008, Graffham and Dziedzoave, n.d.). Relevant products include high-quality cassava flour (HQCF) as a substitute for imported wheat, glucose syrup, and industrial alcohol. The rationale behind these products is that the traditional food market has largely been saturated. Interest from industry exists but there have been bottlenecks in the supply for cassava flour. The solution to this problem originated at FRI and was implemented in conjunction with private manufacturers. It consisted in increasing yields through removing suboptimal farming practices, setting up decentralised processing plants that reduce transport costs and guarantee fresher products, and a new dryer technology developed with partners in Nigeria. This reduced the total cost/kg from GH¢10 to GH¢6.60, but with an acceptable margin for the farmers, who obviously have to trust the level of demand and rely on a certain price stability in order to harvest this crop. End-users were given performance guarantees and processors could draw on a credit facility to ensure the sustainability of the project. This created an entirely new value chain for the industrial use of cassava, and is a good example of how technology can be used to the benefit of poor people. Also, the accreditation of FRI's labs in 2007 by the International Standards

Organisation is evidence that Ghana's research system in select areas is able to operate at world quality standards.

CONCLUSIONS AND RECOMMENDATIONS

This assessment has pursued the question of whether Ghana's research system advances its developmental agenda. In preference of straight talk over nuanced fudging, the answer is no. Since Ghana has been a proud proponent of S&T for longer than most other African countries post-independence, this is sobering in terms of the aspiration to take the continent into the global knowledge economy. The analysis has also raised the question of whether Ghana could in principle do so. The answer is, yes. This concluding section summarises what is wrong with the system and how it could be improved.

Figure 1 depicts a stylised version of the research system and its problems. It focuses on processes, functions, and institutions rather than individual organisations. A few themes emerge. The system receives little by way of inputs and produces little by way of outputs. Problems internal to the organisations addressed in this study include a dearth of professional (research) management, totally inadequate human resource development and misaligned incentive systems, and an absence of regular performance assessment. These are issues the research institutes and universities can and must address themselves. Then there are problems that afflict the system at large: Widespread coordination failures, a dysfunctional IPR system, and again no openness to being reviewed. These are issues external to the organisations reviewed here and must be addressed primarily by government.

It is not possible unambiguously to infer causality from Figure 1. For example, directors of research institutes might argue that if only they had more and better resources, their output would increase and become more relevant. Detractors (in the form of other claimants on public resources) might counter that the nature of the internal problems is such that more inputs would at best be an inefficient way to allocate resources to spur growth and development, and at worst a total waste of money. One might also question how realistic it is to fix problems at the micro (i.e. organisational) level if macro coordination and steering remain problematic or do not happen at all; or, the other way round, what sense it would make to improve overall system capacity if the major knowledge producing organisations in the country cannot get their act together.

This means that piecemeal approaches won't work. This goes for policy, strategy, implementation, and monitoring and evaluation, supported by performance reviews. In sum, although many components of Ghana's

research system perform suboptimally, it is the system at large – in other words the effective interaction between its various components – that does not work. Fixing things here and there is necessary but not sufficient when the whole system needs an overhaul.

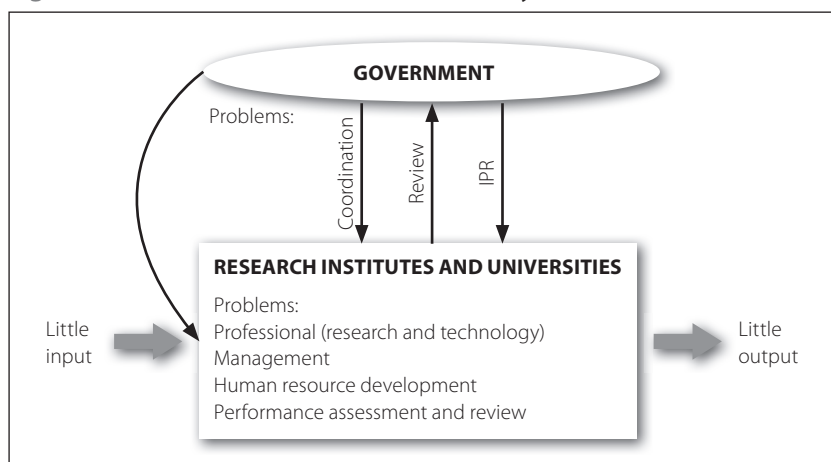
AN OUTLINE OF SOLUTIONS

The most important problem of the system is underfunding. More funding will not by itself (quick-)fix the system; as pointed out, there are other serious problems. But without better resources, none stands a chance of being sustainably solved, and Ghana is unlikely to develop the full range of systemic interactions needed to advance economic development more rapidly. This section first discusses what needs to happen to address this problem, and then how.

The lack of resources can be solved in four complementary ways. First, the government must increase its budgetary allocation to S&T. Knowledge workers need to be well paid. They also need quality equipment and facilities. Such investments only make sense in the context of long-term commitments that necessarily transcend electoral cycles. An increase in spending for a few years, followed by another drought, is futile. In such a case it would be more logical to settle for the more or less permanent low-income status of the country at large.

Second, the government should also consider bringing the entire S&T system under one ministerial roof. The current arrangement whereby responsibility lies with different agencies makes coordination even more difficult in a system that on current standing is not particularly adept at ensuring relevance, efficiency, and effectiveness. It would be easier for one ministry to identify and address coordination and other failures as opposed to several departments overcoming silo mentalities and bureaucratic obstacles. It bears emphasising that if the knowledge economy is as important for Ghana as some key policy documents make it seem, such a ministry must enjoy considerable clout. Of course, legislative fiat will not make STI policy more effective so it will be crucial to ensure that a dedicated ministry has the requisite intellectual and organisational capabilities, supported by political capital, to harness STI activities across existing silos in the government bureaucracy.⁹

Third, the research system must become more efficient. This pertains to staffing levels at the research institutes in particular. The CSIR in particular must take a hard look at its entire business model in each institute, at the Secretariat, and in the organisation as a whole, while not shying away from assessing the opportunity costs of employing people in essentially non-productive positions.

Figure 1 Problems in the Ghanaian Research System

Source Author's own

Fourth, the research system must substantially increase its external income. This requires first and foremost a motivated scientific and academic workforce. Hence effective incentives must be put in place to encourage people to win especially international research tenders and to commercialise technological innovation. A supportive and professionally managed environment is needed in which researchers can rely on upstream (e.g. tender opportunity scanning) and downstream (e.g. marketing, network building, commercialisation, IP management) services whose delivery is essential for the success of core activities.

In an ideal world, all these measures could be directed at the entire system simultaneously. In the real world, this is impossible. What is possible is to open up space for experimenting with institutional and organisational alternatives in select areas. This must be guided by the need to focus on those activities where certain prerequisites exist and where interventions have a better than even chance of succeeding. Such a search for excellence should be based on key factors such as the quantity and quality of highly-skilled human capital and an incipient infrastructure that has supported above-average research or technology performance over the last few years. Differentials in research productivity both across and within institutions provide an entry point for discussions about which parts of the system to select for an experiment. To make this possible the government must abandon its zero-sum game whereby successful income generation on the open market is penalised by a reduction in government subvention.

Not all feasible solutions will be politically palatable. But this is no reason to avoid the discussion. For example, the centralised regulation of academic user fees in the universities prevents the cross-subsidisation of study courses in the sciences and engineering subjects with income from

subjects such as business or law. Likewise, the reluctance to attract top-notch scientists and to reward them with working conditions commensurate with their impact – a lighter teaching load, fully sponsored postgraduate assistants, acceptable lab facilities, and so on – curtails the ability of the universities to increase their presence, even if only selectively, in global knowledge networks.

Across the system, the management of research, technology, people, and their ideas must become more professional. This is an area where decentralisation would likely be inefficient, at least as far as performance review and promotion procedures are concerned. These practices should be standardised across the system so that the best researchers can be associated with, or even migrate to, the most interesting research projects regardless of whether such projects are hosted by an institute other than their own. In essence, it is important that rules and incentives facilitate a market for ideas, seed funding, and project execution so that the most vibrant and relevant parts of the research infrastructure can grow while those that do not produce what is expected of them are allowed to close down. By contrast, the administration of research projects, regardless of size, should be as close to the people actually performing the research as possible.

Finally, the entire system must increase its self-reflexivity. Annual reports should be taken more seriously. Strategic plans that are not updated on a regular basis have little use. Reviews should be undertaken at regular intervals, including through external panels, in order to monitor whether the system is on track.

None of this is easy. But it is possible to achieve it with strong political commitment and the collective determination of key role players. By contrast, continuing the past and current muddling through is tantamount to bidding the knowledge economy farewell. This would not only be bad for Ghana but have wider ramifications for Africa as a whole.

NOTES

- 1 Before the change of government in late 2008, this goal was supposed to be achieved by 2015.
- 2 See www.worldbank.org/kam
- 3 There is not much domestic literature on the issue, and most of it is grey literature presented at conferences etc. without ever being published in (international) journals.
- 4 A new STI policy document is expected for 2010.
- 5 Budget figures are based on the Medium Term Expenditure Framework for 2008-2010 and the annual estimates for 2008 (Republic of Ghana, 2008). This warrants

a caveat. How much money Ghana *actually* invests in its research system is not something one can glean from budget documents. In the past, the discrepancies between estimates and even between approved and disbursed funds in the research system were very significant. Finance administrators of individual research institutes interviewed for this study were adamant that the annual estimates are essentially useless as a planning tool and thus not to be relied on. Perhaps more importantly, discrepancies between approved and disbursed funds *within* a budget year, usually to the disadvantage of the latter, clearly require unconventional efforts to reconcile income and expenditure items.

- 6 See: http://info.worldbank.org/etools/kam2/KAM_page3.asp.
- 7 Due to the poor and irregular availability of annual reports submitted by the CSIR's institutes, 2005 is the most recent year for which information across all institutes was available in 2009. Evidence from the interviews conducted suggests however that little has changed since then; publication output continues to be low across the organisation.
- 8 Utility models are also referred to as "petty patents". They fulfill essentially the same function as patents but are easier to acquire, have a shorter protection term, are usually not examined and thus faster to register, and are cheaper to obtain and maintain.
- 9 I am grateful to an anonymous referee for pointing out this important caveat.

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Labour Productivity, Exports and Skills Formation

Comparing Foreign and Local Firms in Kenyan Manufacturing

Geoffrey Gachino

SUMMARY

This paper uses firm-level panel data from Kenyan manufacturing industry to compare labour productivity, export and skills formation between foreign and local firms. Given the superior productive capabilities and market access of multinational firms, foreign direct investment (FDI) is considered to enjoy greater potential to generate labour productivity, manufactured exports and skilled labour than local firms in poor economies. The paper also examines how FDI affects labour productivity, export and skill formation as one of the determinants, among others. The results generated show that, although local firms generally fared better than foreign firms involving the growth of labour productivity, exports and skilled labour, foreign firms continued to enjoy higher shares. FDI had a positive relationship with labour productivity, exports and skill formation. Overall, it can be claimed that FDI has generally impacted positively on Kenyan manufacturing labour productivity, exports and skilled labour. The positive results of positive impact of FDI have been obtained despite low levels of FDI. The implication is that FDI should be promoted but in tandem with domestic industrial policies which ensure enhanced learning, capability development and innovation.

INTRODUCTION

Developing economies generally learn and upgrade through a combination of imports and domestic development. Local firms' participation in export markets too often arise from spillovers initiated by foreign firms (Morawetz, 1981 Kessing, 1983, Gorg and Greenaway, 2004, Rasiah, 2006). While licensing and imports have characterised the main initial

source of learning enjoyed by Japan, South Korea and Taiwan, it is generally contended that foreign direct investment (FDI) became the major channel of technology transfer in Singapore, Ireland, Israel and Malaysia (Teece, 1977, Rasiah, 1995). While the role of FDI in the appropriation of knowledge, learning and innovation is growing in significance, little consensus exists on its impact on local firms. The anecdotal and analytical evidence on spillovers of tacit and experiential knowledge embodied in human capital in the creation of local firms remains isolated as the measurement of spillovers directly is both a tedious and difficult task (Glass and Saggi, 2002, Rasiah, 2006, Sekkat, 2007, Gachino, 2010a).

The estimation of aggregate spillovers at the national, industry and firm-levels has evolved considerably since Caves (1974) presented arguably the first systematic production function estimation of it. Subsequent empirical work using a similar framework include Blomstrom and Persson (1983), Sjöholm (1997), Aitken and Harrison (1992), Gorg and Greenaway, (2004), Javorcik, 2004, Gachino (2010b), *inter alia*, took this approach to a new dimension by refining the methodology to address locational, industry-type, scale and demonstration effect variables. These works helped improve the original instruments that Caves had used to extend the understanding of spillovers. However, there has been a growing debate over whether the relationships traced through such methodologies can be equated with actual spillovers.

In light of these problems, this paper attempts to examine the role of FDI in domestic development using similar methodologies, but confining the results to the direct consequences. The assessment undertaken here compares labour productivity, exports and skilled labour of foreign and local firms, and explicating the possible dynamics of the results. The potential impact of foreign firms on local firms can of course be interpreted with caveats. Unlike most studies we have deliberately chosen Kenya, which is endowed with very low levels of FDI at the national level, but high in the manufacturing industry. FDI accounted for 0.32 and 0.96 per cent of Gross Fixed Capital Formation in 1994 and 1999 respectively.¹ Foreign equity accounted for 69.1 per cent of manufacturing fixed capital formation in 1994, 66.2 per cent in 1999 and 63 per cent in 2001.² This study enables a policy-relevant assessment of conduct and performance of FDI in a country typically receiving low FDI inflows, which typifies most developing economies.

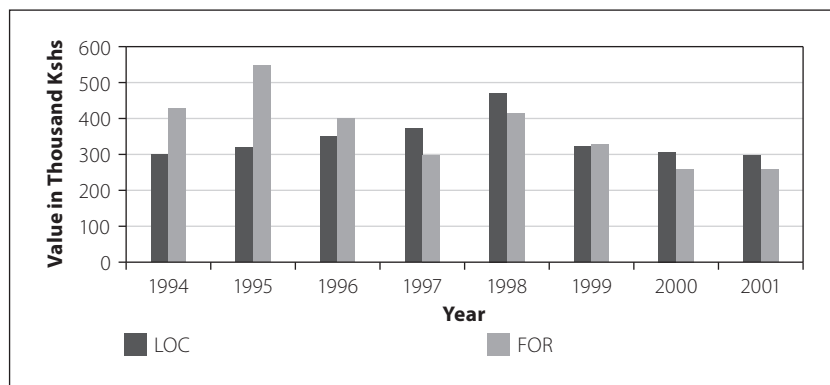
The paper is organised as follows. Section 2 provides a comparison of foreign and local firms with regard to labour productivity, export and skills formation. Section 3 discusses the data and methodology used in the paper. Sections 4, 5 and 6 examine the determinants of labour productivity, exports and skills formation. Section 7 concludes.

COMPARING FOREIGN AND LOCAL FIRMS

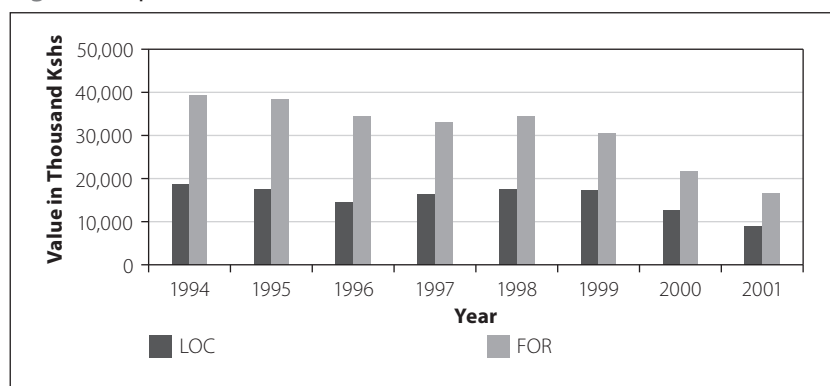
In this section we undertake a comparison between foreign and local firms. While foreign firms enjoyed a high share of fixed capital ownership in Kenyan manufacturing, it is important to examine if the same holds with labour productivity, exports and skilled labour; the three critical variables examined in the paper.

Overall economic stagnation in this period affected value added with consequent effects on labour productivity (Figure 1). Falling exports owing to greater competition abroad aggravated the situation (Figure 2). Macroeconomic constraints arising by a collapse in IMF's structural adjustment package (SAP), massive destruction to physical infrastructure from the El Nino rains and weakening of institutions severely damaged the economy by 1997–1998 (Rasiah and Gachino, 2005, Gachino, 2006). Nevertheless, while FDI inflows slowed down substantially, contrary from projecting a doomsday syndrome, foreign participation increased when viewed from the share of imports of machinery and equipment as that of local firms stagnated. This development reflects the introduction of restructuring efforts in Kenyan manufacturing. The liberalisation process of the 1990s – initiated since the introduction of the structural adjustment package in 1986 – has been accompanied by imports of tariff-free machinery and equipment from abroad, bankruptcies involving uneconomic firms, removal of price controls and the movement of firms away from industries that experienced a dissipation of protection rents. In addition to the natural calamities and institutional failure, liberalisation became painful also because of the lack of efficiently developed capabilities among firms to compete in open competition.

The restructuring enforced following liberalisation also meant that since the mid-1980s, but especially from the 1990s, prevailing firms were restructuring to face external competition. FDI's focus in manufacturing in most African economies shifted from inward-orientation to particularly regional markets. MNCs targeting domestic markets in the past typically geared little production towards export markets beyond neighbouring economies (see Narula and Dunning, 2000). Kenya had in the past benefited from relative political stability to dominate exports to the Common Market of East and Central Africa (COMESA) and African exports to the European Union.³ Kenya still accounted for 42 per cent of COMESA trade and 30 per cent of COMESA exports to the European Union. While the new environment that has emerged since 1995 – a combination of globally driven deregulation following the opening of WTO – is conducive for greater regional market penetration, two major factors have restricted extensive participation by Kenyan firms.

Figure 1 Labour Productivity

Source Computed from data compiled from Ministry of Trade and Industry, Kenya (2002)

Figure 2 Exports

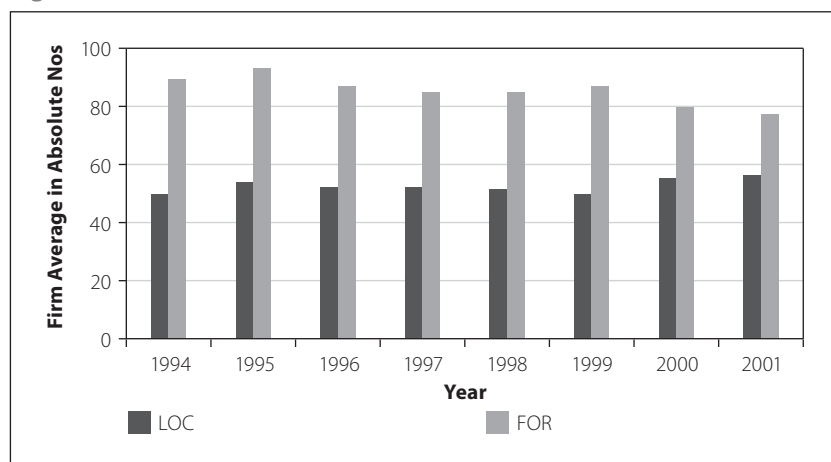
Source Computed from data compiled from Ministry of Trade and Industry, Kenya (2002)

First, the emergence of imports – especially from South Africa (after the end of the Apartheid regime) – has intensified competition. Second, institutional failure in Kenya has severely restricted Kenyan firms' capacity to generate efficient exports.⁴ Hence, although Kenya introduced a number of instruments to promote FDI and export-oriented industrialisation, manufacturing stagnated. Among the instruments introduced to promote exports included Manufacturing Under Bond (MUB) in 1986, which was administered by the Investment Promotion Council (IPC) and exempted firms from duties and value added tax, Export Processing Zones (EPZs) in 1990, Export Promotion Centre and the Export Programme Office (EPPO) in 1992 (Kimuyu, 1999). Exports from Kenya – of both foreign and local firms as shown in Figure 2 – declined in the period 1994–2001. Interviews conducted suggested that institutional failure in Kenya is so severe that several foreign firms have relocated in Uganda despite the relatively weaker natural endowments there.⁵ Despite these constraints, foreign firms continued to enjoy higher value added, exports and skilled labour utilisation in the period 1994–2001.

Foreign firms recorded a decline in value added, exports, skilled labour and labour productivity in the period 1994–2001. Local firms enjoyed a positive growth rate in skilled labour in the same period, albeit it was extremely small. Skilled labour in local manufacturing firms grew by 1.5 and 1.9 per cent per annum over the periods 1994–1997 and 1997–2001 respectively. Nevertheless, foreign firms still accounted for higher endowment of skilled labour throughout the period 1994–2001 than local firms (see Figure 3).

Three important distinctions must be addressed from this section when examining Kenyan manufacturing data econometrically. First, foreign firms continued to enjoy over 60 per cent of fixed capital ownership in the sector between 1994 and 2001. Second, value added, exports, skilled labour and labour productivity of foreign firms in the sector declined in real terms from 1994–2001. Between 1994–1997, the average annual fall in exports, skilled labour, value added and labour productivity of foreign manufacturing firms was –5.5, –1.8, –6.7 and –10.9 per cent respectively. Between 1997–2001, the average annual fall in exports, skilled labour, value added and labour productivity of foreign manufacturing firms was –16.1, –2.1, –6.5 and –4 per cent respectively.⁶ Third, local firms in the sector performed better than foreign firms in this period since they recorded positive growth in a number of variables. Between 1994–1997, the average annual growth in exports, skilled labour, value added and labour productivity of local manufacturing firms was –4.5, 1.5, 5.1 and 7.7 per cent respectively. Between 1997–2001, the average annual growth in exports, skilled labour, value added and labour productivity of local manufacturing firms was –14.4, 1.9, –3.7 and –5 per cent respectively (see also Figures 1, 2 and 3).

Figure 3 Skilled Labour



Source Computed from data compiled from Ministry of Trade and Industry, Kenya (2002)

DATA AND METHODOLOGICAL APPROACH

The empirical information used in this paper is drawn from unpublished plant level data collected in an annual survey by the Ministry of Trade and Industry, Kenya (Department of Company Registration).⁷ The information enabled the creation of a panel database for the period 1994–2001. Unfortunately, data beyond this period was not available since the Ministry ceased collection immediately after 2001. However, this data has been the most comprehensive available and sheds tremendous insight into the issues being examined and where little has been known before.

Given the usual problems associated with missing data, the panel only carries firms' where the information used is complete. In total 420 firms (40 per cent of the population) showed consistent time series responses to all the relevant questions over the period 1994–2001 with the resulting panel of 3,360 observations.

Ownership was defined as foreign when foreign ownership of nominal capital reached at least 10 per cent and local otherwise.⁸ By this definition, 175 firms were classified as foreign and the remaining 245 firms as local. This benchmark was preferred as it also used by the Kenyan national authorities.

Being a poor and underdeveloped economy, Kenya is no different from most Sub-Saharan economies where it is extremely difficult to identify a relevant deflator to convert the nominal data to constant prices. Hence, this paper uses the best that was available. The GDP deflator was used to adjust sales and capital investment. Export values were deflated using export price indices for manufactured goods. The expenditure values of machinery and equipment were deflated using import price indices for machinery and transport equipment.

Owing to the limited frequency of firms in some industries, the dummies were selected at the 2-digit international standard industrial classification (ISIC) level. Of the nine industries that come under the 2-digit level, one was dropped owing to lack of any foreign firms.

Panel data analysis is used here to examine the direct contribution and the impact of foreign presence on labour productivity, export capability and skill formation in Kenyan manufacturing, controlling for time effects and industry specificities. The general model used to analyse the panel data is as follows:

$$Y_{it} = \alpha_i + \sum_{j=1}^k \beta_{ij} X_{ijt} + \varepsilon_{it} \quad (1)$$

Where $i = 1, 2, \dots, n$ denotes a cross sectional unit (a firm), and $t = 1, 2, \dots, t$ denotes a given period. Thus Y_{it} is the value of the dependent variable

for firm i at period t and X_{ijt} is the value of j^{th} non-stochastic explanatory variable for firm i at period t . The random error term ε_{it} is assumed to have a mean of zero and a constant variance. β_{js} are unknown response coefficients to be modeled.

The above framework can be generalised into two basic models; fixed and random-effects models. The two are different in the way the constant is interpreted. In the fixed effects model α_i is captured as the group specific constant term. The assumption in the fixed-effects model is that variations across units can be captured in the differences in the constant term and thus α_i is an unknown parameter estimated. The random-effects model specifies α_i as a group specific disturbance term, similar to α_i . The residual term for random effects can then be expressed as: $\mu_{it} = \nu_i + \varepsilon_{it}$. The component ν_i is the random disturbance defining the i^{th} observation and is constant through time.

Several effects across industries would be expected to correlate with independent variables. For instance, food processing is the most productive and dynamic industry in Kenya and therefore would attract higher foreign presence than other industries. Hence, an empirical model to treat such a correlation explicitly would be required. This is attempted through the introduction of industry and time dummies in panel model specified in equation (1) above, which is then expressed as:

$$Y_{it} = \alpha_i + \sum_{j=1}^k \beta_{ij} X_{ijt} + DUMMY_i + DUMMY_t + \varepsilon_{it} \quad (2)$$

Where $DUMMY_i$ represents the eight industry dummies used here.⁹ $DUMMY_t$ refers to annual time dummies over the years 1994–2001.

Equation (2) formed the basis for the estimation of the determinants of labour productivity, exports and skills formation. Given the nature and amount of data used, it was necessary to undertake several estimates for the purposes of checking consistency, validity and robustness of results across different techniques. Hence, the model was subjected to Ordinary Least Squares (OLS), fixed-effects (FE), random-effects (RE) and Generalised Least Squares (GLS) estimations. In addition, the different techniques allow the modeling of important statistical characteristics – e.g. gross data outliers, heteroscedasticity and autocorrelation – that normally affect econometric data. Preliminary estimations and comparisons using Hausman specification indicated that the random-effects model had more efficient results compared to the fixed-effects model.

OLS and GLS regressions were estimated allowing for differences in approach. The OLS model used robust estimates. Under normal circumstances, three kinds of regressions are commonly known: Standard regression estimates OLS primarily based on predicting the mean; quintile regression

predicts the median; and robust regression performs an initial screening based on spatial distance to eliminate gross outliers prior to computing the estimates using multiple iterations.

The GLS technique is a more rigorous method than the OLS technique, which allows for heteroskedasticity and autocorrelation to be modeled across panels. The method also allows for autocorrelation within panels to be modeled in which case the structure with no autocorrelation, correlation parameter common for all the panels or a unique correlation parameter for each panel can be modeled separately (Green, 2000, Stata, 2003). GLS was estimated allowing for heteroskedasticity and assuming no autocorrelation. All estimations easily passed the White (1980) test for heteroskedasticity.

Finally, random-effects were estimated using GLS models. Given that the model had subsumed internally the treatment of heteroskedasticity and autocorrelation, the regressions were run by assuming homoskedasticity and no autocorrelation. It is possible to make estimations allowing for autocorrelation. For simplicity panel estimates controlling for both heteroskedasticity and autocorrelation were used here since the results with and without the inclusion of these parameters were not significantly different.

The variables used in examining various hypotheses for all the three aspects being addressed (labour productivity, exports and skill formation) are similarly defined. This is done below and in advance to avoid repetition in the later sections. Note however that the actual influence of each variable (hypothesis) is discussed comprehensively in the specific sections. The variables are defined as follows:

Labour productivity was computed as:

VAD/L_{ijt} = Logarithm [Value added/Workforce] of firm i in industry j and year t .

The foreign ownership dummy for firm i in industry j and year t was defined as:

$FDI_{ijt} = 1$ when foreign equity was at least 10 per cent; $FDI_{ijt} = 0$ otherwise.

Foreign presence in the industry was measured as:

$FORPS_{jt}$ = Logarithm of per centage share of foreign output sales to the total output sales for industry j and year t .

Export was measured as:

$EXPORTS_{ijt}$ = Logarithm of export value of firm i in industry j and year t .

Capital was measured as:

$KPTL_{ijt}$ = Logarithm of capital of firm i in industry j and year t .

Skilled labour (comprising scientists, engineers and other technical personnel) was measured as:

$SKILL_{ijt}$ = Logarithm of skilled labour in firm i in industry j and year t .

Investment in new machinery and equipment was measured as:

$INVME_{ijt}$ = Logarithm of expenditure on new machinery and equipment of firm i in industry j and year t .

The Herfindahl-Hirschman index was used to denote concentration and it was measured as:

$HERFijt$ = sales of firm i /Total sales in industry j and year t .

Scale was measured as:

$SCALE_{ijt}$ = Firm i 's production in industry j and year t /Average production of entire manufacturing industry in year t .

Capacity utilisation was measured as:

$LCAPUTL_{ijt}$ = Actual Output/Potential Output of firm i in industry j and year t .

In addition to the explanatory variables above, time and industry dummies were also used. $DUMMY_j$ represents industry dummies used to capture non-observable industry specific effects like general demand conditions. $DUMMY_t$ represents time dummies for each year to capture productivity shocks in the economy.

All the independent variables were tested for possible statistical correlation. The results of the correlation tests showed that none of the independent variables posted high and significant correlation, and hence faced no multicollinearity problems.

For each of the econometric technique used, the model was repeated twice. The first estimation included time dummies only while the second estimation included both time and industry dummies.

In addition to panel estimations, separate regressions were run by ownership and technology gap. The classification used to separate firms by ownership was the same as *FDI* used in the paper. The technology gap was computed as ratio of a firms' expenditure on machinery and equipment to the industry average of *FDI* on expenditure on machinery and equipment. The mean of this ratio was then obtained and on the basis of this mean all the firms whose ratio was above this mean were all classified as firms with low technology gap while those with a ratio below this mean were classified as firms with low technology gap.

DETERMINANTS OF LABOUR PRODUCTIVITY

This section examines the impact of *FDI* on labour productivity. Based on equation (2) above, the specification of the equation to examine the impact of foreign presence on labour productivity in Kenyan manufacturing can be formulated as follows:

$$VAD / L = F\{FDI_{ijt}, EXPORTS_{ijt}, KAPTL, SKILL_{ijt}, INVME_{ijt}, HERF_{ijt}, SCALE_{ijt}, CAPUTL_{ijt}, DUMMY_j, DUMMY_t, \alpha_i, \varepsilon_{it}\} \quad (3)$$

Given the argument taken in the paper that foreign firms are more productive than local firms, the relationship between labour productivity and *FDI* is expected to be positive. A positive sign would show a positive impact of *FDI* on labour productivity in Kenya. *FDI* inflows into a host country is likely to result in increased technological know how in superior machinery and equipment, products, management and organisation (Haddad and Harisson 1993, Harisson 1996, Aitken and Harisson 1999, Cheung and Lin, 2004, Sekkat, 2007).

EXPORTS variable is expected to have a positive effect on labour productivity. The process of exporting exposes firms to cutting edge technologies from international markets. The networks established overseas are sometimes sources of new knowledge and new machinery, all of which could raise labour productivity. There is also the pressure for exporting firms to maintain continuous innovation since competition in international markets is intense. *KAPTL* is expected to have a positive effect on labour productivity. Capital investment is necessary for production and thus an increase in capital investment holding other things constant would raise labour productivity. *SKILL* is expected to have a positive and statistically significant correlation with labour productivity since technically qualified personnel is necessary to drive learning, innovation and production. *INVME* is expected to have a positive correlation with labour productivity

as machinery is an important driver of production. *HERF* can either be positive or negative. It would be negative if less concentrated industries generate low labour productivity and positive if more concentrated industries produce high labour productivity. *SCALE* can have either a positive or negative impact on productivity. If industries involved enjoy economies of scale – i.e. there is a minimum efficiency scale involved – they would be correlated with high labour productivity (Pratten, 1971, Scherer, 1992). However, in light of the significance of flexibility offered by scope, small firms have performed better in some industries (Rasiah, 1995). Hence, the relationship between scale and labour productivity can be either positive or negative. *CAPUTL* is expected to have a positive correlation with labour productivity.

Table 1 presents the OLS, GLS and random-effects results of all firms in the panel sample. *FDI* was positively correlated with labour productivity in all three models. The elasticity of labour productivity with *FDI* was relatively high with the coefficient of *FDI* having the expected sign that was statistically highly significant. When the model was estimated using time dummies and industry dummies the estimated coefficients were 0.29 with OLS, 0.32 with GLS and 0.37 with random effects, suggesting that a rise of 100 per cent in equity participation by FDI would raise labour productivity by between 29 and 37 per cent.

Exports had a positive effect on labour productivity. The inclusion of industry dummies alongside time dummies produced statistically highly significant coefficients, 0.17 with GLS and random effects, and 0.18 with OLS. Increasing exports by 100 per cent would increase labour productivity by between 17 and 18 per cent, which makes sense as exporting firms must be efficient and productive.

Capital investment was also positively correlated with labour productivity. Using the models with time and industry dummies, capital had a coefficient of 0.17 with OLS, 0.22 with GLS and 0.20 with random effects implying that an increase of 100 per cent of capital in a firm was likely to increase labour productivity by between 17 and 22 per cent.

Contrary to expectation, skilled labour force was negatively correlated with labour productivity. The results were highly significant and became even more so with the introduction of industry dummies. Interestingly, this implied that an increase of 100 per cent of skilled labour force in a firm was likely to reduce labour productivity by between 25 and 32 per cent. Two plausible reasons may account for this. First, given the economic stagnation Kenya has faced in the period 1994–2001, there has been a relative decline in the hiring of skilled labour suggesting saturation of the factor of production in relation to labour productivity. The second could be a consequence of a fall in the share of skilled labour demanded by these

industries suggesting either a trend towards deskilling or the preference for acquiring low wage experienced workers who enjoyed the skills, but not the qualifications. Interviews suggest that the latter trend is also common as firms retrenched skilled workers to hold wages down in light of increasing competition and falling profit margins.¹⁰

The value of machinery and equipment had the expected sign and was statistically highly significant. An increase of 100 per cent in *FDI* incidence was likely to raise labour productivity by between 12 and 14 per cent.

Table 1 Determinants of Labour Productivity: Panel Estimates

Variable	OLS	OLS	GLS	GLS	Ran. eff.	Ran. eff.
FDI	0.26*** (5.16)	0.29*** (5.78)	0.31*** (6.22)	0.32**** (6.48)	0.35*** (6.76)	0.37*** (7.21)
EXPTS	0.19*** (8.46)	0.18*** (8.10)	0.18*** (8.33)	0.17*** (8.53)	0.19*** (8.44)	0.17*** (7.63)
KAPTL	0.14*** (5.29)	0.17*** (6.62)	0.17*** (7.13)	0.22*** (9.32)	0.18*** (6.59)	0.20*** (7.66)
SKILL	-0.25*** (-6.20)	-0.25*** (-6.23)	-0.27*** (-6.78)	-0.29*** (-7.33)	-0.31*** (-7.73)	-0.32*** (-7.67)
INVME	0.18*** (6.57)	0.13*** (4.99)	0.17*** (6.79)	0.12*** (5.22)	0.17*** (6.41)	0.14*** (5.27)
HERF	0.22*** (3.89)	0.63 (1.46)	0.19*** (3.62)	0.56 (1.53)	0.23*** (4.10)	0.38 (0.87)
SCALE	0.57*** (9.74)	-0.42 (-0.94)	0.57*** (12.56)	-0.19 (-0.50)	0.59*** (10.00)	-0.19 (-0.42)
CAPUTL	-0.03 (-0.29)	-0.08 (-0.78)	-0.05 (-0.51)	-0.09 (-0.92)	-0.08 (-0.77)	-0.13 (-1.30)
Constant	0.50 (0.84)	2.80* (1.92)	-0.57 (0.99)	1.90 (1.40)	-0.82 (-1.35)	2.41* (1.63)
R squared					0.50	0.32
Time Dummies	YES	YES	YES	YES	YES	YES
Industry Dummies	NO	YES	NO	YES	NO	YES
F-Test	32.73***	26.97***				
Log Likelihood			-792.54	-753.15		
Wald-Test for GroupWise Heteroscedasticity.			734.79***	1091.71**	535.63***	489.42***
No. of observations	562	562	562	562	562	562
Note: T-statistics are presented in parentheses. *, **, *** represent 10%, 5% and 1% levels of significance respectively.						

Source Computed from data compiled from Ministry of Trade and Industry, Kenya

Introduction of the time and industry dummies reduced both the significance and magnitude of its coefficients.

The results of concentration (*HERF*) and scale variables were not very robust but that both had positive signs that were highly significant statistically only when time dummies were used. Their magnitudes and significance levels changed tremendously when industry dummies were introduced. Without industry dummies *HERF* had a positive coefficient whose value ranged between 0.19 and 0.23 and were significant at 1 per cent. The results were statistically insignificant when industry dummies were used; suggesting that high concentration was influenced by scale economies rather than defensive conduct by firms. Scale was statistically highly significant and had a positive coefficient of 0.57 with OLS and GLS and 0.59 with random-effects when only time dummies were used. The introduction of industry dummies transformed the coefficient from positive to negative with all the three estimation techniques but was statistically insignificant. Capacity utilisation did not have the expected sign and was not significant.

EFFECTS USING TECHNOLOGY GAP

The impact of *FDI* on labour productivity was also examined with the inclusion of a variable to capture technology gap. Using the classification of low and high technology gap firms introduced in Section two, over 70 per cent of all the firms came under high technology gap while 30 per cent under a low technology gap. The implication for this is that most of the local firms in the Kenyan manufacturing have a relatively high technology gap with foreign firms.

Table 2 presents the OLS, GLS and random-effects results. Once again all the estimation techniques showed very consistent results. The results show that in the case of firms with high technology gap, the coefficients of foreign presence for all the firms was 0.39 with OLS, 0.40 with GLS and 0.47 with random effects, all of which were statistically highly significant. The results obtained with low technology gap were somewhat interesting in that the coefficient of *FDI* was small in magnitude – 0.24 with OLS, 0.34 with GLS and 0.29 with random effects – despite being statistically highly significant. These results tend to support the argument that a threshold point of technological gap rather than a simple contention of lower gaps is important in determining technology diffusion and learning which is consistent with Findlay's (1978) conjecture in his technology-transfer model based on Veblen and Gerschenkron's catching-up hypothesis.

Findlay postulated that as far as the disparity was not too wide to deter learning process in a developing country, a relatively wide gap created the necessary pressure for change in the developing country. Rasiah (2003) had

Table 2 Determinants of Labour Productivity:
Panel Estimates using Technology Gap

Variable	OLS High	OLS Low	GLS High	GLS Low	Ran. eff. High	Ran. eff. Low
FDI	0.39*** (5.81)	0.24*** (3.11)	0.40*** (6.47)	0.34*** (4.15)	0.47*** (7.14)	0.29*** (3.09)
EXPTS	0.15*** (5.50)	0.24*** (5.81)	0.17*** (7.21)	0.15*** (3.19)	0.15*** (5.64)	0.17*** (3.49)
KAPTL	0.19*** (5.78)	0.07 (1.64)	0.24*** (9.06)	0.19*** (3.88)	0.20*** (6.20)	0.19*** (3.62)
SKILL	-0.19*** (-3.58)	-0.39*** (-5.62)	-0.24*** (-5.14)	-0.50*** (-6.72)	-0.24*** (-4.66)	-0.44*** (-5.28)
INVME	0.13*** (4.07)	0.09* (1.72)	0.10*** (3.84)	0.18*** (2.93)	0.14*** (4.49)	0.12* (1.88)
HERF	0.63 (0.99)	0.74 (0.88)	0.67 (1.42)	-0.02 (-0.03)	0.76 (1.22)	0.001 (0.00)
SCALE	-0.31 (-0.40)	-0.61 (-0.93)	-0.65 (-1.15)	0.26 (0.42)	-0.42 (-0.56)	0.20 (0.26)
CAPUTL	-0.12 (-0.74)	-0.06 (-0.41)	-0.07 (0.52)	-0.16 (-1.07)	-0.12 (-0.78)	-0.22 (-1.30)
Constant	2.05 (0.66)	-0.41 (-0.18)	3.08 (1.21)	2.58 (1.20)	1.88 (0.62)	-
R squared					0.59	0.45
Time Dummies	YES	YES	YES	YES	YES	YES
Industry Dummies	YES	YES	YES	YES	YES	YES
F-Test	24.32***	7.57***				
Log Likelihood			-515.24	-188.53		
Wald-Test for GroupWise Heter.			1077.81***	169.66***	541.62***	3767.00***
No. of observations	399	163	399	163	399	163
Note: T-statistics are presented in parentheses. *, **, *** represent 10%, 5% and 1% levels of significance respectively.						

Source Computed from data compiled from Ministry of Trade and Industry, Kenya

argued that the wider gap also offered greater room for learning following Hirschman's (1958) convincing work over the dynamic effects *FDI* can create through the imbalances it causes initially and when supply capabilities respond to meet them (Rasiah, 2003). Abramovitz (1986) seminal contribution in his catching up model advanced a similar argument contending that countries lagging behind were in a position to generate growth, but only if their social capabilities were sufficiently developed.

Export had the expected sign and was statistically highly significant when both time and industry dummies were used (Table 2). Machinery and equipment was only statistically significant at the 10 per cent level when industry dummies were added. Capital was only statistically significant when industry dummies were dropped. Skilled labour remained negative and statistically highly significant even with industry dummies included. *HERF*, *SCALE* and *CAPUTL* were all not statistically significant.

DETERMINANTS OF EXPORTS

This section examines the impact of *FDI* on exports. Based on equation (2) above, the specification of the equation to examine the impact of foreign presence on exports in Kenyan manufacturing can be formulated as follows:

$$EXPORTS_{ijt} = F\{FDI_{ijt}, FORPS_{ijt}, KAPTL_{ijt}, INVME_{ijt}, SCALE_{ijt}, HERF_{ijt}, CAP_{ijt}, DUMMY_j, DUMMY_t, \alpha_i, \varepsilon_{it}\} \quad (4)$$

Given that foreign firms in poor economies are generally considered more efficient and possess higher technology, the sign for *FDI* is expected to be positive. For the same reasons advanced earlier, *FDI* is expected to be a potential source of superior machinery and equipment, intangible assets and easier access to export markets (Caves, 1974, Rasiah, 1995, Aitken and Harisson, 1999, Sizhog, 2010).

FORPS can have either a positive or negative sign. A positive relationship is obtained when foreign firms' sales in the domestic market offer the competitive drive (including demonstration effects) and scale for stimulating exports. A negative sign could emerge if foreign sales merely substitute imports and drive out local firms without stimulating exports.

KALF is expected to have a positive effect on exports. Productive capital investment is necessary for raising productivity levels and hence its increase holding other things constant is likely to raise exports. *SKILL* and *INVME* are expected to have a positive effect on exports for the same reasons advanced for labour productivity. *HERF* and *SCALE* are expected to have either a positive or negative sign for the same reasons advanced for labour productivity. Similarly, *CAP* is expected to have a positive sign.

The results were estimated based on OLS, GLS and random effects and are shown in Table 3. Despite the slight variations in the coefficients produced by the three estimations, they were comparable and their significant levels in all the three estimate techniques follow the same trend, which makes all the estimates consistent and robust across the techniques.

The results show that *FDI* enjoyed positive correlation with exports, but only when the industry dummies were not included. *FDI* had a positive coefficient and was significant at 10 per cent in OLS and GLS but at 5 per cent using random-effects without industry dummies. The implication is that an increase in *FDI* by 100 per cent points was likely to increase export capability by between 17 and 19 per cent. The implication for this is that *FDI* increased the propensity to export. However, when industry dummies were included the coefficient reduced in size drastically and was not statistically significant.

Foreign presence had a positive impact on exports with the GLS approach. A positive coefficient of 0.57 was estimated and was statistically highly significant. OLS had an estimated coefficient of 0.72 significant at 5 per cent while random effects had an estimate coefficient of 0.68 significant at 1 per cent. These coefficients were relatively large implying that an increase of 100 per cent in foreign presence at the industry level was likely to increase the exports by between 57 and 72 per cent. The results weakened when industry dummies were added, the estimated coefficients reduced substantially in magnitude, switching from positive to negative and becoming statistically insignificant.

Capital investment had the expected sign and was statistically highly significant. The estimated coefficients by all the three procedures were similar. With the inclusion of industry dummies the OLS and GLS estimated a coefficient of 0.19 while that of GLS remained the same as when industry dummies were not included. An increase in capital investment by 100 per centage points was likely to increase exports by between 19 to 22 per centage points.

The skilled workers variable had positive coefficients and was statistically highly significant when industry dummies were included. The coefficients of skilled workers were 0.75 with GLS and random-effects estimations, and 0.74 with OLS estimations. The implication of these results is that if a firm increases its employment of skilled workers by 100 per cent, then it was likely to increase its exports by between 74 and 75 per cent. Operating an exports market requires upgrading and innovation, which typically requires the use of scientists, engineers and technicians. Given that the relationship between labour productivity and skilled workers was negative, this result suggests that inward-oriented firms enjoy higher value added per worker than firms that export; foreign competition reducing profit value added margins though higher intensity of professional and technical workers are necessary to participate in export markets.

In all the three techniques used, investment in machinery and equipment had the expected sign and was statistically highly significant. The coefficients increased slightly in magnitude and remained positive and

Table 3 Determinants of Exports: Panel Estimates

Variable	OLS	OLS	GLS	GLS	Ran. eff.	Ran. eff.
FDI	0.19* (1.86)	0.15 (1.46)	0.17* (1.85)	0.09 (0.94)	0.17*** (1.84)	0.11 (1.14)
FORPS	0.72** (2.59)	-0.06 (-0.04)	0.57*** (2.82)	-0.14 (-0.11)	0.68*** (2.61)	-0.07 (-0.05)
KAPTL	0.21*** (4.02)	0.19*** (3.65)	0.22*** (4.58)	0.22*** (4.57)	0.21*** (4.30)	0.19*** (3.87)
SKILL	0.64*** (8.34)	0.74*** (9.58)	0.65*** (9.15)	0.75*** (10.64)	0.64*** (8.89)	0.75*** (10.35)
INVME	0.23*** (4.22)	0.25*** (4.59)	0.21*** (4.25)	0.22*** (4.62)	0.23*** (4.46)	0.26*** (5.00)
HERF	0.07 (0.59)	-0.23 (-0.26)	0.07 (0.68)	-0.002 (-0.00)	0.13 (1.15)	-0.13 (-0.16)
SCALE	0.21* (1.68)	0.90 (0.97)	0.19 (1.60)	0.55 (0.68)	0.28** (2.34)	0.66 (0.76)
CAPUTL	-0.64*** (-3.08)	-0.71*** (-3.40)	-0.59*** (-3.13)	-0.72*** (-3.86)	-0.56*** (-2.87)	-0.65*** (-3.35)
Constant	0.37 (0.23)	1.70 (0.23)	0.94 (0.74)	3.19 (0.52)	-0.08 (-0.05)	2.29 (0.34)
R squared					0.39	0.45
Time Dummies	YES	YES	YES	YES	YES	YES
Industry Dummies	NO	YES	NO	YES	NO	YES
F-Test	20.72***	17.11***				
Log Likelihood			-1169.18	-1143.22		
Wald-Test for GroupWise Heteroskedasticity.			411.76***	528.39***	356.59***	434.03***
No. of observations	565	565	565	565	565	565
Note: T-statistics are presented in parentheses. *, **, *** represent 10%, 5% and 1% levels of significance respectively.						

Source Computed from data compiled from Ministry of Trade and Industry, Kenya, 2002.

statistically highly significant when industry dummies were added. An increase of 100 per centage points in machinery and equipment expenditure would increase firms export by between 22 to 26 per centage points. It is therefore reasonable to imagine that increased expenditure on machinery and equipment – especially more efficient ones – would in turn support manufacture for export.

The effect of scale on employment was positive and significant at 10 per cent with OLS and at 5 per cent with random-effects. This was observed

only with time dummies included and the estimated coefficient was 0.21 with OLS and 0.28 with random effects. Although the coefficients estimated with industry dummies were positive they were not significant.

The results obtained for industry concentration were not significant. Capacity utilisation had negative coefficients in all three estimations. The estimated coefficients were -0.71 with OLS, -0.72 with GLS and -0.65 with random-effects when industry dummies were added. This means that an increase in capacity utilisation by about 100 per cent would lower exports by between 65 and 72 per cent. This inverse relationship seems to be a result of the shakeout occurring in Kenya as a consequence of economic stagnation and external competition.

EFFECTS USING SEPARATION OF OWNERSHIP

The effect of *FDI* on export capability was also examined by taking both domestic and foreign firms separately and the results are presented in Table 4. In this case foreign investment was taken as foreign presence determined at the industry level. Somewhat comparable results to those observed above were obtained. The results obtained for the domestic firms were as expected, positive and significant at 1 per cent but only when industry dummies were excluded. The coefficient estimated was 0.54 with random effects, 0.57 with OLS and 0.55 with GLS implying that an increase of 100 per centage points in foreign presence at the manufacturing industry was likely to increase exports by between 54 and 57 per cent. With industry dummies the results were not robust. Although the coefficient of foreign presence remained positive they were not statistically significant.

A similar trend was observed in foreign firms. The results of *FDI* were statistically highly significant when industry dummies were dropped. The coefficients obtained were 0.53 with GLS, 0.59 with random effects and 0.60 with OLS robust. Both sets of firms – both local and foreign – seem to benefit from foreign presence in generating exports. The positive result could be the result of either the low levels of investment, which have not intensified the competition for factor inputs and export markets or the catalytic role foreign presence has offered in stimulating exports of foreign and local firms in Kenya

Capital, skill, machinery and equipment all had the expected results, generally statistically highly significant with positive coefficients. The estimated results of industry concentration were not significant for both local and foreign firms. The results show that industry concentration does not influence export behaviour of Kenyan manufacturing firms. Scale turned out to be a very important determinant of export involving domestic firms when industry dummies were excluded. The estimated coefficients were

0.75 with GLS, 0.77 with random effects and 0.79 with OLS meaning that an increase of 100 per cent in scale would increase exports by between 75 and 79 per cent. However, the results obtained with industry dummies were not statistically significant. Scale was not important in foreign firms. The estimated results were only as expected in OLS and random-effects regressions and without industry dummies. The results obtained with OLS were 0.23 – significant at 10 per cent – while that obtained with random effects was 0.28 – significant at 5 per cent. An increase in scale in foreign firms by 100 per cent was likely to increase exports in foreign firms by between 23 and 28 per cent. Although scale was still important in foreign firms' participation in export markets, it appears that foreign small and medium firms enjoy greater flexibility and agility to specialise on the basis of scope and hence enjoy stronger penetration in export markets than local small and medium firms.

There was also a wide variation in the results obtained between local and foreign firms on capacity utilisation. With the exception of OLS, the results obtained with industry dummies were significant at 10 per cent while the results obtained without industry dummies were significant at 1 per cent for all the techniques.

Without industry dummies the coefficients obtained averaged 0.71 and with industry dummies they averaged about 0.37 implying that an increase of 100 per cent in capacity utilisation would increase exports in local firms by 71 and about 37 per cent when industry dummies were dropped and used respectively. In the case of foreign firms, capacity utilisation affected exports negatively. This was significant in all the estimates regardless of whether industry dummies were included or not.

EFFECTS USING TECHNOLOGY GAP

The impact of *FDI* on export was also repeated controlling for technology gap (see Table 5). In this analysis all the firms domestic and foreign were included. It was interesting to note that once again firms classified to have a high technology gap had significant results. *FDI* enjoyed a statistically highly significant coefficient of 0.51 with random effects, 0.54 with OLS and 0.56 with GLS when industry dummies were added. An increase of 100 per cent in *FDI* would increase export by between 51 and 56 per cent to the firms with high technology gap. Conversely, the firms classified to have low technology gap had negative results that were significant in the case of GLS and random effects. The latter could be the case of foreign firms expanding more in more dynamic industries with a consequent rise in learning and technology diffusion, and falling in mature old industries. The results obtained with foreign presence were not significant in both cases. Similarly,

Table 4 Determinants of Exports: Panel Estimates by Ownership

Variable	OLS	OLS	GLS	GLS	Ran. eff	Ran. eff
	Local	Local	Local	Local	Local	Local
FORPS	0.57*** (2.70)	0.55 (0.54)	0.55*** (3.42)	0.32 (0.36)	0.54*** (2.64)	0.30 (0.29)
KAPTL	0.12*** (3.52)	0.10*** (3.16)	0.12*** (3.80)	0.09*** (2.99)	0.12*** (3.59)	0.10*** (3.10)
SKILL	0.18*** (3.00)	0.15*** (2.84)	0.19*** (3.47)	0.15*** (2.92)	0.21*** (3.57)	0.18*** (3.30)
INVME	0.36*** (7.94)	0.34*** (8.18)	0.40*** (9.92)	0.41*** (11.07)	0.36*** (8.15)	0.37*** (8.86)
HERF	-0.02 (-0.24)	0.19 (0.28)	-0.06 (-0.69)	0.59 (0.94)	0.005 (0.06)	0.44 (0.63)
SCALE	0.79*** (8.34)	0.29 (0.41)	0.75*** (8.98)	-0.06 (-0.09)	0.77*** (8.40)	0.012 (0.02)
CAPUTL	0.71*** (3.23)	0.30 (1.43)	0.72*** (3.49)	0.35* (1.77)	0.70*** (3.29)	0.38* (1.81)
Constant	-3.22** (-2.33)	0.97 (0.18)	-3.24** (-2.72)	1.68 (0.34)	-3.20* (-2.38)	1.78 (0.32)
Time Dummies	YES	YES	YES	YES	YES	YES
Industry Dummies	NO	YES	NO	YES	NO	YES
F-Test	26.67***	24.94***				
Log Likelihood			-1000.00	-958.04		
R-Squared Overall					0.42	0.49
Wald-Test for GroupWise Heteroscedasticity.			562.73***	763.24***	392.32***	514.23***
No. of Observations	549	549	549	549	549	549
Variable	Foreign	Foreign	Foreign	Foreign	Foreign	Foreign
FORPS	0.60** (2.07)	-0.09 (-0.06)	0.53** (2.55)	-0.15 (-0.13)	0.59** (2.19)	-0.03 (-0.02)
KAPTL	0.17*** (3.05)	0.12** (2.39)	0.17*** (3.51)	0.14*** (3.06)	0.17*** (3.40)	0.13*** (2.57)
SKILL	0.72*** (8.38)	0.82*** (9.97)	0.75*** (9.65)	0.83*** (11.48)	0.72*** (8.96)	0.83*** (10.80)
INVME	0.24*** (4.10)	0.29*** (4.92)	0.21*** (4.05)	0.24*** (4.81)	0.23*** (4.27)	0.29*** (5.20)
HERF	0.02 (0.20)	-0.30 (-0.33)	0.004 (0.04)	-0.03 (-0.04)	0.08 (0.73)	-0.18 (-0.22)
SCALE	0.23* (1.66)	0.88 (0.93)	0.14 (1.10)	0.53 (0.66)	0.28** (2.18)	0.70 (0.78)
CAPUTL	-0.69*** (-3.33)	-0.82*** (-3.99)	-0.64*** (-3.42)	-0.83*** (-4.70)	-0.62*** (-3.16)	-0.78*** (-4.04)
Constant	1.78 (1.20)	2.92 (0.40)	2.20** (1.92)	4.18 (0.69)	1.22* (0.88)	2.88 (0.42)
Time Dummies	YES	YES	YES	YES	YES	YES
Industry Dummies	NO	YES	NO	YES	NO	YES
F-Test	21.70***	19.41***				
Log Likelihood			-1123.77	-1085.15		
R-Squared Overall					0.40	0.47
Wald-Test for GroupWise Heteroscedasticity.			400.76***	559.66***	352.25***	468.30***
No. of Observations	541	541	541	541	541	541

Note: T-statistics are presented in parentheses.
 *, **, *** represent 10%, 5% and 1% levels of significance respectively.

Source Computed from data compiled from Ministry of Trade and Industry, Kenya, 2002.

capital, skill, machinery and equipment all had the expected signs and were significant at varying significant levels 1, 5 and 10 per cent. The results of industry concentration and scale were not significant. Capacity utilisation again produced a negative correlation with the exports for both high and low technology gap firms but significant in the case of low technology gap only.

Table 5 Determinants of Exports: Panel Estimates using Technology Gap

Variable	OLS High	OLS Low	GLS High	GLS Low	Ran. eff. High	Ran. eff Low
FDI	0.54*** (4.11)	-0.26 (-1.54)	0.56*** (4.98)	-0.24* (-1.69)	0.511*** (4.14)	-0.28* (-1.79)
FORPS	4.57 (1.08)	-0.70 (-0.04)	2.88 (1.01)	-0.05 (-0.03)	4.21 (1.07)	-0.03 (-0.02)
KAPTL	0.12* (1.91)	0.39*** (4.43)	0.12** (2.13)	0.42*** (5.56)	0.11* (1.84)	0.39*** (4.82)
SKILL	0.91*** (9.67)	0.43*** (2.91)	0.95*** (11.06)	0.47*** (3.72)	0.92*** (10.14)	0.45*** (3.32)
INVME	0.22*** (3.49)	0.30** (2.59)	0.20*** (3.72)	0.28*** (2.79)	0.23*** (3.90)	0.30*** (2.82)
HERF	-0.43 (-0.33)	1.21 (0.66)	-0.34 (-0.31)	1.38 (0.90)	-0.43 (-0.36)	1.28 (0.76)
SCALE	1.75 (1.14)	0.59 (0.39)	1.39 (1.20)	0.49 (0.40)	1.58 (1.11)	0.49 (0.36)
CAPUTL	0.007 (0.02)	-1.30*** (-4.53)	-0.03 (-0.10)	-1.33*** (-5.48)	-0.02 (-0.07)	-1.27*** (-4.84)
Constant	-24.99 (-1.35)	2.73 (0.26)	-16.51 (-1.20)	1.83 (0.21)	-22.56 (-1.30)	-
R Squared					0.50	0.49
Time Dummies	YES	YES	YES	YES	YES	YES
Industry Dummies	YES	YES	YES	YES	YES	YES
F-Test	16.53***	6.42***				
Log Likelihood			-797.25	-282.51		
Wald-Test for GroupWise Heter.			492.83***	158.45***	381.18***	3437.35***
No. of Observations	401	164	401	164	401	164
Note: T-statistics are presented in parentheses. *, **, *** represent 10%, 5% and 1% levels of significance respectively.						

Source Computed from data compiled from Ministry of Trade and Industry, Kenya, 2002.

DETERMINANTS OF SKILLED LABOUR

This section examines the impact of *FDI* on skilled labour. Based on equation (2) above, the specification of the equation to examine the impact of foreign presence on skilled labour in Kenyan manufacturing can be formulated as follows:

$$SKILL_{ijt} = F\{FDI_{ijt}, FORPS_{ijt}, KAPTL_{ijt}, INVME_{ijt}, EXPORTS_{ijt}, SCALE_{ijt}, HERF_{ijt}, CAPUTL_{ijt}, DUMMY_j, DUMMY_t, \alpha_i, \varepsilon_{it}\} \quad (5)$$

Given that foreign firms are generally considered more efficient and possess superior technology than local firms, the expected sign for *FDI* is positive. A positive coefficient would suggest a positive elasticity between *FDI* and skilled labour in Kenyan manufacturing. Foreign firms employ most skilled workers; they have better training schemes, and machinery and equipment. Such training is likely to impart host country workers with the latest product and production techniques, managerial and organisational know how and marketing skills. *FDI* can also stimulate growth and development of a number of ancillary domestic enterprises, which can help create jobs in host economies. Skilled workers could leave foreign firms and join local firms a process which would further increase the diffusion of techniques and skill formation (Gershenberg, 1987, Globerman, 1979, Harisson, 1996, Aitken and Harisson, 1999, Haddad and Harisson, 1993, Pavcnik, 2003). Of course the converse can also happen if foreign firms poach skilled workers from local firms.

FORPS can have either a positive or negative sign. It is expected to be positive if rising foreign presence is accompanied by greater absorption of skilled labour. A negative sign can be expected if the rising share of foreign presence occurs in the face of overall stagnation in domestic sales, in which case it fails to stimulate a rise in the absorption of skilled labour. Given the stagnation faced by the manufacturing sector in Kenya over the study period this is very likely. With firms reducing skilled labour utilisation in the face of stagnation, local firms could of course seek to hire retrenched skilled workers who may have gained tacit knowledge from foreign firms. Hence, the separate regressions by ownership may show a positive relationship between foreign presence and skilled labour in the local firms' regressions undertaken later.

KAPTL is expected to have a positive effect on skill formation. Productive capital investment is necessary for raising productivity and thus an increase in capital investment holding other variables constant would increase skill labour. *INVME* is expected to have a positive sign since investment in new machinery and equipment would require skilled labour to run them.

EXPORTS is expected to have a positive effect on skill formation as exporting firms require skilled technical labour to drive learning and innovation to compete in export markets. *HERF* and *SCALE* can either be positive or negative for the same reasons advanced for labour productivity. *CAPUTL* is expected to have a positive sign.

The empirical results showed a positive correlation between *FDI* and skilled labour. Estimates obtained with OLS were robust but that with GLS were not as robust as they were only significant when industry dummies were excluded (Table 6). The random-effects approach did not produce statistically significant results without industry dummies. However, with industry dummies included random effects had the expected results that were positive and statistically highly significant. The coefficient posted was 0.10, which implies that an increase of 100 per cent in *FDI* will raise skill formation by 10 per cent. This was more or less the same as the results obtained without dummies in the case of GLS and OLS of between 9 and 14 per cent. However, the elasticities involving the significant results show marginal influence.

The results obtained with foreign presence were negative. All techniques produced negative coefficients that were significant when industry dummies were added, which implies foreign presence and skilled labour absorption were not positively correlated.

Exports, capital and capacity utilisation all had a positive effect on skill formation. With industry dummies included in both OLS and random effect estimations, exports had a positive coefficient of 0.22 while that of GLS was 0.23. This means that an increase of 100 per centage points in exports was likely to increase skill formation by between 22 and 23 per cent. With industry dummies capital had the expected results: 0.18 with random effects, 0.19 with OLS and 0.22 with GLS, implying that an increase of 100 per cent in a firm's capital would raise skill labour by between 18 and 22 per cent. Capacity utilisation was also an important factor in skill labour absorption. With industry dummies included the OLS, random-effects and GLS estimates were 0.34, 0.35 and 0.45 respectively. Capacity utilisation seemed to have the largest coefficients in magnitude and thus the largest influence on skilled labour followed by exports and then capital investment. An increase in the capacity utilisation of 100 per cent would raise skilled labour by between 34 and 45 per cent.

The coefficients involving machinery and equipment expenditure were not significant and had negative signs. Industry concentration had a positive coefficient without dummies in the case of OLS and GLS and significant at 5 and 1 per cent respectively, suggesting that concentrated industries hire more skilled labour, which given the positive and statistically significant coefficient involving scale (only when industry dummies were

Table 6 Determinants of Skilled Labour: Panel Estimates

Variable	OLS	OLS	GLS	GLS	Ran. eff.	Ran. eff.
FDI	0.14** (2.56)	0.07 (1.41)	0.09* (1.75)	0.07 (1.43)	0.08 (1.45)	0.10** (1.98)
FORPS	-0.44*** (-3.12)	-0.22 (-0.29)	-0.51*** (-4.43)	-0.19 (-0.34)	-0.49*** (-3.40)	-0.17 (-0.23)
EXPTS	0.19*** (8.53)	0.22*** (10.42)	0.21*** (10.10)	0.23*** (12.16)	0.20*** (8.89)	0.22*** (10.35)
KAPTL	0.20*** (7.77)	0.19*** (7.32)	0.214*** (8.86)	0.22*** (9.56)	0.19*** (7.19)	0.18*** (6.85)
INVME	0.03 (1.21)	-0.03 (-1.03)	0.02 (0.86)	-0.05** (-2.23)	0.01 (0.36)	-0.03 (-0.20)
HERF	0.14** (2.26)	0.03 (0.06)	0.20*** (3.44)	-0.06 (-0.14)	0.09 (1.47)	0.07 (0.15)
SCALE	0.28*** (4.38)	-0.12 (-0.26)	0.33*** (5.40)	-0.10 (-0.26)	0.21*** (3.15)	-0.17 (-0.35)
CAPUTL	0.28*** (2.65)	0.34*** (3.16)	0.40*** (3.99)	0.45*** (4.55)	0.37*** (3.44)	0.35*** (3.32)
Constant	-0.19 (-0.24)	1.04 (0.28)	-0.70 (-0.98)	0.15 (0.05)	0.32 (0.39)	0.87 (0.23)
R squared					0.36	0.44
Time Dummies	YES	YES	YES	YES	YES	YES
Industry Dummies	NO	YES	NO	YES	NO	YES
F-Test	24.10***	19.32***				
Log Likelihood			-814.89	-777.15		
Wald-Test for GroupWise Heter.			522.20***	963.74***	311.84***	417.62***
No. of observations	565	565	565	565	565	565
Note: T-statistics are presented in parentheses. *, **, *** represent 10%, 5% and 1% levels of significance respectively.						

Source: Computed from data compiled from Ministry of Trade and Industry, Kenya, 2002.

dropped), was understandable. Scale-driven industries obviously restricted the number of firms to appropriate the synergies associated with minimum scale efficiency. Hence, industries with large concentration of firms did not seem to have raised entry barriers defensively. The estimated coefficients were 0.21 with random effects, 0.28 with OLS and 0.33 with GLS. An increase of 100 per cent in scale would imply perhaps increase skill formation by between 21 and 33 per cent.

EFFECTS USING SEPARATION OF OWNERSHIP

The effect of *FDI* on skilled labour was also examined separately by ownership (Table 7). The effect of foreign presence was negative and significant involving foreign firms but only when industry dummies were excluded. Although less robust, the inverse relationship further confirms the results above that market stagnation has forced foreign firms to reduce the use of skilled labour. Given the stagnation over the period studied it seems that foreign presence seems to have increased owing to the greater stagnation in the sales of local firms domestically alongside falling numbers of skilled labour hired by foreign firms; which seems to have highly significant industry effects. As can be observed in Table 7 an increase of 100 per cent in foreign presence was likely to decrease skilled labour numbers by between 49 and 55 per cent in foreign firms.

The results obtained for local firms were as expected only with GLS and random-effects techniques and when industry dummies were not added. It was nearly significant with OLS. Local firms have benefited slightly from the contraction in foreign firms by hiring more skilled workers. Without taking industry specificities into consideration, it can be stated that an increase in foreign presence by 100 per cent would increase skilled labour by between 31 and 38 per cent in local firms.

With the exception of a few, most of the other determinants had the anticipated effect on skill labour absorption involving both local and foreign firms. Exports of both local and foreign firms had the expected positive coefficients: Around 0.10 with industry dummies in the case of local firms and above 0.20 in the case of foreign firms. These coefficients are expected as foreign firms are more export-oriented than local firms. Similarly, capital had a positive effect on skill labour absorption in both cases but higher in foreign than local firms. Based on the average coefficient of the three techniques the coefficient of capital for the local firms was 0.07 while that of the foreign firms was about 0.20. Local firms showed higher capital utilisation coefficients than foreign firms, which was expected as foreign firms faced significantly greater decline than local firms. Based on the average of the coefficients estimated using the three techniques local firms' average was 0.46 while that of foreign firms was 0.36.

The expenditure on machinery and equipment had statistically highly significant and positive coefficients when industry dummies were included in the case of local firms: The coefficients were 0.10 with GLS, 0.15 with random-effects and 0.19 with OLS. The coefficients involving foreign firms were statistically significant and positive, but only when industry dummies were dropped and their influence was marginal: 0.07 with GLS, 0.09 with random-effects and 0.06 with OLS. This is a result of a contraction of skilled

Table 7 Determinants of Skilled Labour: Panel Estimates by Ownership

Variable	OLS	OLS	GLS	GLS	Ran. eff	Ran. eff
	Local	Local	Local	Local	Local	Local
FORPS	0.25 (1.59)	-0.03 (-0.04)	0.38*** (2.94)	-0.12 (-0.19)	0.31** (2.04)	0.06 (0.07)
EXPTS	0.10*** (3.15)	0.10*** (2.93)	0.10*** (3.21)	0.08*** (2.67)	0.11*** (3.57)	0.11*** (3.30)
KAPTL	0.07*** (2.82)	0.06** (2.33)	0.10*** (4.69)	0.09*** (4.00)	0.07*** (2.81)	0.07** (2.53)
INVME	0.19*** (5.31)	0.19*** (5.39)	0.15*** (5.13)	0.15*** (5.11)	0.15*** (4.48)	0.16*** (4.46)
HERF	0.11 (1.53)	-0.38 (-0.68)	0.12 (2.31)	-0.30 (-0.65)	0.08 (1.21)	-0.33 (-0.61)
SCALE	-0.31*** (-4.25)	0.31 (0.56)	-0.36*** (-5.19)	0.02 (0.04)	-0.36*** (-5.04)	0.213 (0.39)
CAPUTL	0.40** (2.46)	0.46*** (2.72)	0.34*** (2.43)	0.37*** (2.60)	0.50*** (3.15)	0.55*** (3.37)
Constant	-1.52 (-1.47)	-1.82 (-0.41)	-1.58** (-1.84)	-0.22 (0.06)	-1.83** (-1.83)	-2.18 (-0.50)
R-Squared Overall					0.18	0.19
Time Dummies	YES	YES	YES	YES	YES	YES
Industry Dummies	NO	YES	NO	YES	NO	YES
F-Test	8.26***	5.80***				
Log Likelihood			-817.13	-810.14		
Wald-Test for GroupWise Heter.			186.42***	256.65***	115.38***	123.76***
No. of observations	549	549	549	549	549	549
Variable	Foreign	Foreign	Foreign	Foreign	Foreign	Foreign
FORPS	-0.50*** (-3.66)	-0.20 (-0.28)	-0.49*** (-4.74)	-0.14 (-0.23)	-0.52*** (-3.91)	-0.16 (-0.23)
EXPTS	0.19*** (9.03)	0.22*** (11.07)	0.20*** (10.38)	0.23*** (12.57)	0.18*** (8.96)	0.22*** (10.80)
KAPTL	0.20*** (8.13)	0.21*** (8.82)	0.21*** (9.34)	0.21*** (9.74)	0.19*** (7.60)	0.18*** (7.37)
INVME	0.06** (2.28)	0.03 (1.07)	0.07** (2.55)	0.01 (0.30)	0.09*** (3.08)	0.04 (1.43)
HERF	0.16*** (2.71)	0.03 (0.08)	0.20*** (3.55)	0.11 (0.29)	0.17*** (2.89)	0.048 (0.11)
SCALE	0.34*** (5.31)	-0.09 (-0.21)	0.35*** (6.08)	-0.18 (-0.45)	0.32*** (5.03)	-0.17 (-0.38)
CAPUTL	0.22** (2.18)	0.34*** (3.48)	0.32*** (3.28)	0.41*** (4.28)	0.26*** (2.61)	0.33*** (3.31)
Constant	0.34 (0.47)	0.47 (0.14)	-0.44 (-0.73)	0.07 (0.02)	0.24 (0.34)	0.72 (0.21)
R-Squared Overall					0.44	0.50
Time Dummies	YES	YES	YES	YES	YES	YES
Industry Dummies	NO	YES	NO	YES	NO	YES
F-Test	30.26***	27.07***				
Log Likelihood			-746.10	-715.49		
Wald-Test for GroupWise Heter.			628.39***	875.34***	417.44***	510.04***
No. of observations	541	541	541	541	541	541

Note: T-statistics are presented in parentheses.
 * ** *** represent 10%, 5% and 1% levels of significance respectively.

Source Computed from data compiled from Ministry of Trade and Industry, Kenya, 2002.

labour as foreign firms were restructuring by increasing their expenditure on new machinery and equipment.

The results obtained for scale were statistically highly significant in both the local and foreign firms' regressions but only when industry dummies were dropped; this was expected given the industry-specific dimensions of scale. However, the coefficients were negative involving local firms and positive involving foreign firms. Local firms were obviously hiring skilled labour in non-scale based industries and shedding or not hiring new skilled labour in scale-based industries. The coefficients of scale involving local firms were -0.31 with OLS, and -0.36 with both GLS and random-effects.

The coefficients involving foreign firms were positive: 0.34 with OLS, 0.35 with GLS and 0.32 with random-effects. The positive correlation between scale-driven industries and skilled labour absorption suggests that foreign firms that are large have hardly shed skilled labour. This is to be expected given the generally positive relationship between scale and exports involving foreign firms.

EFFECTS USING TECHNOLOGY GAP

Separate regressions using separation of the data by technology gap were run against the dependent variable of skilled labour and the results are presented in Table 8. The sample with firms classified by low technology gap generated positive results when industry dummies were used. All estimations produced a coefficient of 0.47 and was statistically significant at 1 per cent. An increase of 100 per cent *FDI* incidence involving firms with a low technology gap would increase skill labour absorption by about 47 per cent.

The coefficients involving *FDI* for firms with a high technology gap were negative and significant but marginal in the case of GLS and random effects. This result suggests that firms in industries facing a high technology gap are little engaged in expanding skilled labour. It may be that firms in the high technology gap sample are becoming increasingly capital-intensive. This could also be influenced by the fact that foreign firms – which dominate the low technology gap sample – enjoy a slightly higher positive elasticity with skilled labour as shown by the coefficients of the panel estimations involving the integrated sample.

Foreign presence was not statistically significant involving both the low and high technology gap samples. Exports had the expected signs for both category of firms. The coefficients of the sample with high technology gap were 0.24 with OLS and random effects, and 0.25 with GLS. The coefficients involving the low technology gap sample were 0.15 with OLS, and 0.16 with GLS and random-effects. Exports seemed to have a stronger effect involving

Table 8 Determinants of Skilled Labour: Panel Estimates by Technology Gap

Variable	OLS High	OLS Low	GLS High	GLS Low	Ran. eff. High	Ran. eff. Low
FDI	-0.09 (-1.30)	0.47*** (5.08)	-0.17*** (-2.98)	0.47*** (5.97)	-0.13** (-2.00)	0.47*** (5.56)
FORPS	-1.91 (-0.91)	0.07 (0.07)	-1.20 (-1.14)	0.15 (0.18)	-1.79 (-0.88)	0.14 (0.15)
EXPTS	0.24*** (9.97)	0.15*** (2.96)	0.25*** (11.77)	0.16*** (3.58)	0.24*** (10.41)	0.16*** (3.32)
KAPTL	0.23*** (7.53)	0.05 (0.97)	0.21*** (8.71)	0.05 (1.11)	0.22*** (7.49)	0.07 (1.28)
INVME	-0.07** (-2.12)	-0.02 (-0.28)	-0.04* (-1.80)	-0.07 (-1.09)	-0.06* (-1.86)	-0.04 (-0.69)
HERF	0.515 (0.81)	-0.38 (-0.35)	0.05 (0.11)	-0.38 (-0.40)	0.48 (0.77)	-0.30 (-0.30)
SCALE	-0.66 (-0.86)	0.79 (0.90)	-0.34 (-0.61)	0.73 (0.96)	-0.56 (-0.77)	0.67 (0.85)
CAPUTL	0.64*** (4.23)	-0.07 (-0.40)	0.57*** (4.24)	-0.12 (-0.74)	0.65*** (4.49)	-0.09 (-0.54)
Constant	8.27 (0.89)	0.31 (0.05)	5.47 (0.92)	-	7.54 (0.85)	-
R squared					0.54	0.40
Time Dummies	YES	YES	YES	YES	YES	YES
Industry Dummies	YES	YES	YES	YES	YES	YES
F-Test	20.45***	4.39***				
Log Likelihood			-515.38	-194.75		
Wald-Test for GroupWise Heter.			871.82***	3016.40***	447.20***	2625.75***
No. of observations	401	164	401	164	401	164
Note: T-statistics are presented in parentheses. *, **, *** represent 10%, 5% and 1% levels of significance respectively.						

Source Computed from data compiled from Ministry of Trade and Industry, Kenya, 2002.

the high technology gap sample with *FDI*; supporting the learning arguments in the paper.

Capital and capacity utilisation had the expected results only involving the high technology gap sample. Machinery and equipment expenditure had a negative relationship with skilled labour, which were statistically significant at 5 and 10 per cent.

CONCLUSIONS

This paper examined the impact of FDI on labour productivity, exports and skilled labour using panel data estimation techniques. Unlike most existing works on FDI, the study was undertaken on Kenya, which is a poor economy where overall FDI levels in GFCF was extremely low but high in manufacturing, and in a period when the manufacturing sector as well as the economy in general was facing economic stagnation.

The results obtained showed that although local firms generally fared better than foreign firms involving the growth rates of labour productivity, exports and skilled labour, foreign firms continued to enjoy higher shares throughout the period under study. It was also observed that FDI had a positive correlation with labour productivity, exports and skilled labour. Overall, it can be argued that FDI had a positive impact on Kenyan manufacturing labour productivity, exports and skilled labour. Interestingly, the higher technology gap sample was also associated with stronger statistical relationship with labour productivity and exports.

These results were obtained using aggregate data from a poor economy faced with economic stagnation and institutional failure. A further disaggregation of the data and the use of relationships specifying firms using value chains and controlling for institutional and systemic variables will be necessary to improve the results. Quite clearly this will be a much more ambitious task but with wide policy implications. On the basis of the results generated, a plausible implication of the study is that FDI should be further promoted but in tandem with domestic industrial policies which ensure enhanced learning, capability development and innovation.

NOTES

- 1 Computed from the World Bank data (2001).
- 2 Computed from data supplied by the Ministry of Trade and Industry, Nairobi.
- 3 COMESA was formed in 1994 to promote regional integration. It had a membership of 20 countries in 2003.
- 4 Kenyan firms also faced a nominal interest rate of 20 per cent and severe failures afflicting power supply, road infrastructure and telecommunication in 2002 (Interviews by author, 4–16 April 2002).
- 5 Interviews conducted by the author in Nairobi, in 2002.
- 6 Computed from data supplied by the Ministry of Trade and Industry, Nairobi.
- 7 We are grateful to the Ministry of Trade and Industry for allowing us access to the data.
- 8 This definition follows that of OECD and UNCTAD. Other benchmarks taken by other researchers include Sjöholm (1997) who had a benchmark 15 per cent of equity owned

by foreigners, Haddad and Harrison (1993) considered foreign firms as those with at least 5 per cent equity owned by foreigners while Djankov and Hoekman (1998) had a bench mark of 20 per cent.

- 9 As noted earlier, one industry was dropped owing to the absence of foreign firms in that industry.
- 10 Interviews by the author in 2002: Competition and economic stagnation seems to have reduced profit margins of both foreign and local firms, which have responded by various cost-cutting measures.

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Innovative Approaches to Industrial Utilisation of Cassava in a Developing Economy

Abolaji D. Dada, Godwin A. Ali, Oladele O. Afolabi, and Williams O. Siyanbola

SUMMARY

Nigeria has remained the world's leading economy in the production of cassava for about two decades. Nevertheless, the industrial utilisation of this agricultural produce has remained low. We synthesise the findings of an extensive literature on some innovative approaches to this challenge. There is a need for policy learning on how Nigeria can sustain global leadership in cassava production by an efficient utilisation of cassava in the industrial sector to transform the Nigerian Small and Medium Enterprises (SMEs). The Nigerian government is encouraging private sector participation in developing technologies for expanded use of cassava as raw materials in the food and non-food industries. The development of the sector will require activities in capacity building, further product development, fabrication and transfer of processing technologies to target beneficiaries, and development of clusters to supply identified markets. To sustain Nigeria's global leadership in cassava production, the paper also suggests the need to map out the cassava value chain in the cassava sectoral innovation system. This will help, no doubt, to strengthen the links between the supply and demand in the most effective way.

INTRODUCTION

Advancement is not new to industrial economies in the level of technical know-how and widespread application of technological innovations resulting in high productive capability in agriculture and industry. As technology makes goods and services cheaper to produce, the quantity available at a given price can increase greatly, stimulating processes of economic growth. This is not so however, in developing nations like Nigeria where

these technologies are not often available to farmers. Users also find such innovations difficult to maintain even when they are appropriate for local conditions due to lack of maintenance and skill training.

For more than a decade, Nigeria has remained the global leader in cassava production, with an annual production of 42 million metric tonnes (FAO, 2007). However, cassava processing, market efficiencies and productivity have remained stumpy due to poor technological development (Odebode, 2008, Dada *et. al.*, 2009). The rate of cassava processing has not matched the rate of its production in Nigeria (Oke, 2005). In Nigeria, it is estimated that only 16 per cent of cassava root were utilised as an industrial raw material, out of which 10% was used as chips in animal feed, 5 per cent was processed into syrup concentrate for soft drinks and the remaining 1 per cent was processed into high quality cassava flour used in biscuit and confectionary (Kormawa and Akoroda, 2003). The transformation of cassava processing from the traditional food crop to an industrial raw material will complement the shift of cassava production from a low-yielding, famine reserve crop, to a high-yielding cash crop. The strategies revolve around the technological-solution to the constraints and harnessing opportunities in cassava production. Processing is important for the marketing of cassava, and reduces the bulk, extends shelf life thereby reducing transportation cost. Fresh cassava roots have low value per unit weight; whereas processing adds value to it and therefore increases the market value. In addition, fresh roots of some cassava cultivars contain cyanogens which are reduced or eliminated through processing.

This paper, therefore, synthesises the findings of an extensive literature on cassava transformation for Nigeria, with the aim of making useful policy suggestions on how technology can be harnessed to enhance Nigeria's sustained global leadership in cassava production.

SCIENCE AND TECHNOLOGY IN AGRICULTURE

Science and technology activities include scientific and technological research, experimental development, scientific and technological services, innovation and diffusion (Ilori *et al.*, 2002). S&T is the key to progress and industrial growth in today's increasingly knowledge-driven world. New product development is a fundamental factor for stimulating and supporting economic growth, and constitutes a key issue for wealth generation in many industrialised nations. The contribution of S&T to economic development has become increasingly important as a result of new waves of technologies, with generic characteristics that enable them to affect almost all facets of human endeavour (Adeoti and Adeoti, 2005). According to

Odebode (2008), the gap between developed and developing countries in the area of agricultural production can be attributed largely to differences in the level of technological development, adaptation and transfer process. In the two centuries since the industrial revolution, the driving force behind the global rise in wealth has been the issue of increased productivity.

Technology has made pertinent contributions to national progress and its usefulness has attained universal recognition both at national and international levels. Agricultural research and technological improvements are crucial to increased agricultural productivity and returns to farmers, making market more efficient. For instance, in the 1970s, cassava output per hectare in the developing countries increased by 80 per cent with the introduction of new technologies (Paulino 1990). Major factors responsible for cassava expansion in Nigeria are the new high-yielding Tropical Manioc Selection (TMS) varieties developed by the International Institute of Tropical Agriculture (IITA) that boosted cassava yield by 40 per cent without fertilizer application (IITA, 2004). A market-oriented development of agro-enterprises to take up and process cassava tubers and add value to it in order to enhance its commercialisation is imperative, hence, the importance of S&T in cassava processing in Nigeria.

Figure 1 Cassava Root Crops



Source http://upload.wikimedia.org/wikipedia/commons/8/8f/Manihot_esculenta_dsc07325.jpg

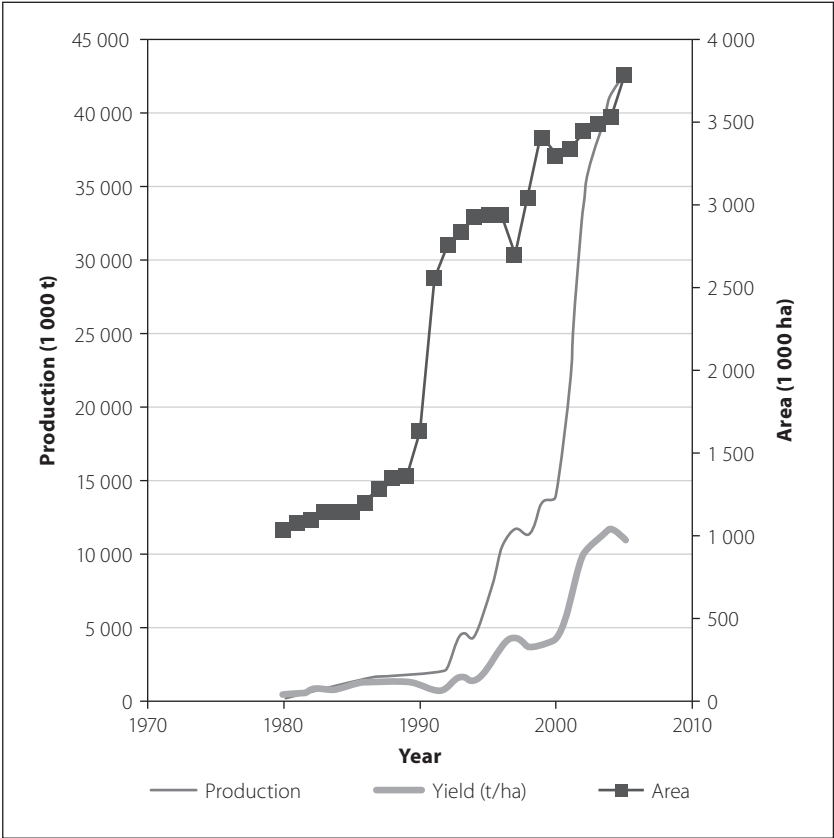
CASSAVA PRODUCTION IN NIGERIA: THE TREND

Cassava (see Figure 1) is grown in over 90 countries worldwide providing food, and is a source of livelihood for over 500 million people, mostly in developing countries. In terms of the total land area that is planted to cassava, 50 per cent is in Africa, 30% in Asia, and the rest in Latin America. FAO estimates the 2007 output to be 212 million tonnes, 4 million tonnes above the figure in 2006. There has been a general increase in production over time, with fluctuations across countries. Global production has been increasing continuously since 1999. In the early 1960s, Africa accounted for close to 42 per cent of world cassava production. By the early 90s, Africa produced almost half of the world cassava output. This increase was attributed to higher production, particularly, by Nigeria and Ghana, which increased production fourfold. The availability of new Tropical Manioc Selection (TMS) cassava varieties by IITA increased cassava production in Africa by 40 per cent without using any fertilizer, with Nigeria becoming the largest producer in the world, followed by Brazil.

In the mid 1980s, the Nigerian government invested in measures to diffuse the improved TMS varieties among the farmers. By the late 1980s, the TMS diffusion in Nigeria had become Africa's agricultural success story. In 1989, IITA researchers conducting the Collaborative Study of Cassava in Africa (COSCA) found that farmers in 60 per cent of the surveyed villages planted the TMS varieties. Cassava production in 2003 was about 34 million metric tonnes, from a total land area of about 3.1 million hectares, giving an average yield of about 11 tonnes per hectare (RMRDC, 2004). Nigeria has a large market and overall economic development for cassava composite flour if developed where SMEs are expected to play pivotal roles in the development process. Currently, Nigeria is the world's largest producer of cassava with about 42 million metric tonnes per annum (FAO, 2007) (Figure 2) and 34 million metric tonnes per annum (FAO, 2004) (Figure 3).

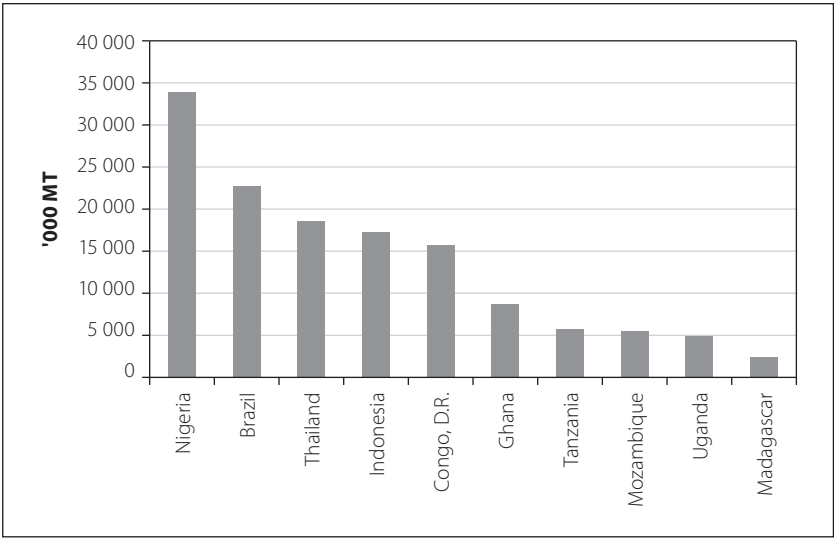
Nigeria's target of cassava production is 60 million tonnes by the year 2020. Other organisations that have contributed to the development and improvement of cassava in Nigeria include National Root Crops Research Institute (NRCRI), a Federal Government Institute under the Federal Ministry of Agriculture and Water Resources, with the main mandate of conducting research into the genetic improvement, production, processing, storage utilisation and marketing of root and tuber crops of economic importance. The Root and Tuber Expansion Programme which is an initiative of the Federal Government of Nigeria, is also involved in promoting accelerated expansion of cassava production in Nigeria. Other key factors that lead to the growth of cassava production in Nigeria are the higher consumer demand for cassava by rural and urban households which encouraged the farmers to cultivate

Figure 2 Cassava Production Trend, Area Cultivated and Yield in Nigeria, 1980–2005



Source Plotted from FAO Data (2007)

Figure 3 Leading World Producer of Cassava



Source FAO (2004)

more land to cassava. Secondly, the use of the mechanical grater to prepare *gaari* reduces labour, especially female labour, from processing for planting more cassava. Thirdly, the cassava mealy bug epidemic devastation was averted by Africa-wide biological control programme.

Cassava is produced largely by small-scale farmers, using local farm tools. The average land-holding is less than two hectares for most farmers; land and family labour remain the essential inputs. Land is held on a communal basis, inherited or rented; cases of outright purchase of land are rare. Capital is a major limitation in cassava production; while few farmers have access to rural credit. Furthermore, government intervention and the efforts of non-governmental organisations in the cassava subsector have led to a number of measures that support the production, processing and marketing of cassava, dating back to the 1970s (FMANR, 1997).

Increased demand has put a lot of pressure on the production of cassava in Nigeria. The principal mode of cassava utilisation is the traditional food processing at home or in cottage and small-scale operations. Eighty eight per cent of cassava produced in African countries, including Nigeria, is consumed in the form of human food in different forms (FAO, 2004). In Nigeria, this is mainly in the form of *gaari*, and to a lesser extent *fufu*. The demand for chips especially for animal feeds is just emerging and is very low. However, there is an appreciable level of demand for other products such as starch for the textile, pharmaceutical, pulp and paper industries; adhesives for packaging industries and flour for bakery and confectionery industries. It is estimated that more than 40 million tonnes of cassava would be needed to service industries that would produce the listed products to satisfy the needs (RMRDC, 2004).

Cassava supplies the bulk of energy intake in Southern Nigeria and can be processed into many different forms. Roots can be eaten raw or boiled, processed into granulated flour used to make “*gaari*” or pastes, or processed to produce vital raw materials such as adhesives, alcohol and starch, which are useful in the livestock, feed, alcohol/ethanol, textile, confectionery, wood, food and soft drinks industries. Nigeria is the largest producer in the world, followed by Brazil. From 1961 to 1965, Nigeria produced about 7.8 million tons of cassava per year and was the fourth-largest producer in the world after Brazil, Indonesia, and the Congo (FAO, 2004). This ranking changed in 1995 and since then Nigeria has been the largest producer worldwide.

CASSAVA PROCESSING AND MARKETING OPPORTUNITIES

Cassava is a perishable commodity once harvested, with a shelf life of less than three days. This has important implications: Marketing systems for

fresh roots have to be well integrated with production. It also means that processing is far more important than for other commodities. More than 40 per cent of cassava is currently processed, mainly into traditional food products. Processing provides a means of producing shelf stable products (thereby reducing losses), adding value at a local rural level and reducing the bulk to be marketed. Cassava losses in 2002 were of the order of 19 million tonnes from a total continent wide production of 101 million tonnes (FAO, 2003). These figures are based on national estimates of physical losses, but losses in cassava need to be considered more broadly. The losses can occur in several ways: (a) Physical losses of the dried commodity (cassava chips) range from 3 to 15 per cent (b) Losses in handling of fresh roots occur as a result of price discounting because of the age of the commodity in anticipation of physical losses; these can be as high as 90 per cent for cassava that is more than three days old at the wholesale level (c) Losses due to change in use. For example, if harvested fresh roots cannot be marketed within two days of harvest they may be processed into dried products, which have lower value (d) Lost potential because of non-harvesting.

In order to gain real benefits from using improved technologies, effective linkages are essential between processors and markets. However, such linkages do not always exist, particularly in remote areas. Farmers have not always been able to set up linkages themselves and may need assistance. According to Westby *et al.* (2002), small- and medium-scale enterprises (SMEs) can play important roles in market chains by providing access to capital, processing facilities and commercial transport, relevant manufacturing experience, proven business record, proven record on quality, an understanding of marketing issues and a willingness to support farmers and processors for mutual gain. Quality standard marks may also be used by enterprises in marketing in order to promote appropriate approaches to quality assurance through ratification of quality standards to protect consumers and assure them of the quality of products.

The key role of the public sector in supporting activities to the private sector include the documentation and promotion of best practices and approaches to commercialisation; providing information on post-harvest technologies and how to access them; supporting access to market information (at various levels) and guidance on how to access market information; support to preparation of business plans; support to development of regional and national strategies to commercialise cassava; facilitating access to technical support for micro, small- and medium-scale enterprises and equipment manufacturers; policy guidance in support of commercialisation and support to development and application of food standards for cassava products, combined with guidance concerning labeling. The financial

returns of investments in the cassava sub-sector will depend on specific product being prepared and the market being accessed.

Efficiencies may be gained in providing backstopping support through a coordination unit. The emphasis of the intervention is mainly in terms of soft infrastructure to support private sector involvement in the commodity. Too much of the world's food harvest is lost to spoilage and infestations on its journey to the consumer. In developing countries, where tropical weather and poorly developed infrastructure contribute to the problem, losses are sometimes of staggering proportions. Losses occur in all operations from harvesting through handling, storage, processing and marketing. They vary according to the influence of factors such as the perishability of the commodity; ambient temperature and relative humidity which determine the natural course of decay; fungal and bacterial decay; damage by pests (insects, rodents and birds); the length of time between harvesting and consumption and practices of post-harvest handling, storage and processing.

Most post-harvest handling, processing and marketing systems in Nigeria operate at a rudimentary level and present few opportunities for farmers, processors and traders. Post-harvest handling of cassava is the largest constraint to increasing cassava production in the country. Post-harvest activities such as processing and marketing can provide much needed employment for those who exit the agricultural sector. Research on policies, institutions, and technologies to strengthen the development of rural agro-enterprises directly contributes to the strengthening of the rural economy even within a contracting agricultural sector. To facilitate the adoption of cassava as viable raw material, the highly perishable cassava roots need to be transformed into stable products with a longer shelf life. Such product can be cassava chips or cassava flour. Its production technology is simple and inexpensive and can be adopted by farmers. In Nigeria, small-scale farmers have formed associations for processing cassava into flour that is sold to biscuit factories. Others are producing chips for the ethanol factory. Processed cassava products must compete in markets with grain products, so lowering costs of production is essential to its survival as an industrial crop. Developing a strategy that will contribute to food security and socio-economic growth and development would entail the existence of a growing demand (market) for cassava. This can occur when its unique characteristics are exploited in a specific end use market or cassava becomes economically more attractive for a particular use than do competing products. An immediate concern would be to identify and analyse the current uses and the potential markets for cassava and its products.

However, to make such opportunities operational, more research on appropriate technologies to store, transport, process and ensure product quality will be necessary. The economic impact of post-harvest research

investments is therefore highly encouraging, and should not be discriminated against in funding allocations. In many developing countries, including Nigeria, the private sector does not provide sufficient research funding to overcome market barriers or access new markets. Therefore, the public sector should play a catalytic role in overcoming market-related post-harvest problems. The reduction of the cyanide potential in cassava is another example of where post-harvest research has had an important effect on food safety and this is particularly important in Nigeria. Grating and sun drying cassava roots causes substantial losses in total cyanogens and reducing the grate size leads to more complete hydrolysis of the cyanogenic glucosides into non-glucoside cyanogens if the grates do not dry up too fast. Cassava can be processed into many products of commercial importance.

These products can be classified into primary and secondary products (FIIRO, 2008). The primary products are those obtained directly from cassava roots, while the secondary products are obtained by further processing of the products or the by-products. Some of the primary products include 'Gaari', Cassava Starch, Detoxified Cassava Flour, 'Fufu', Cassava Chips, Cassava Pellet, Fermented Cassava Flour (Lafun). Secondary Products from cassava include Ethanol, Cassava Noodles, Tetracycline, Weaning Food, Glue or Adhesive, Tapioca, Glucose Syrup. Cassava finds application in a number of industrial products that require S&T application. The steps involved in the production of some major cassava agro-industrial products are as discussed below.

CASSAVA COMPOSITE FLOUR

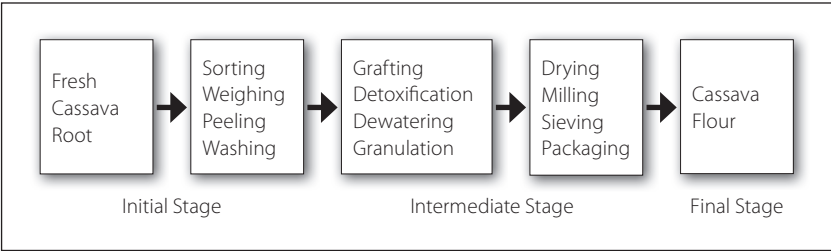
The composite flour programme was initiated by the Food and Agriculture Organisation (FAO) of the United Nations in 1964. It was conceived primarily to develop bakery products from locally available crops, particularly in those countries which could not meet their wheat requirements. The bakery products obtained from such formulation were of good quality and similar in some of their main characteristics to that of whole wheat flour bread. Since then, efforts have been made in many countries to produce bread by conventional methods from wheat flour to which other flours such as cassava flour were added. For instance, research done at the International Institute of Tropical Agriculture (IITA), Nigeria and the Katholieke Universiteit Leuven (KUL) also showed the possibility of baking bread using cassava flour and locally available ingredients. A method for producing higher quality cassava flour suitable for baking has also been developed. The cassava flour was substituted for wheat flour at 20 per cent to produce good quality bread; it was used at 100 per cent level to produce sausage roll, cassava queen cakes, cassava cookies, cassava biscuits (Figure 4).

Figure 4 Various Cassava Food Products



Source http://ngurumanmaarif.blogspot.com/2011_06_01_archive.html, <http://4.bp.blogspot.com/-91zyIPbgV4/Tfsam6cbW7I/AAAAAAAAAS8/22E2laM0J74/s1600/tenebo.jpg>

Figure 5 Production Processes/Technology of Cassava Flour



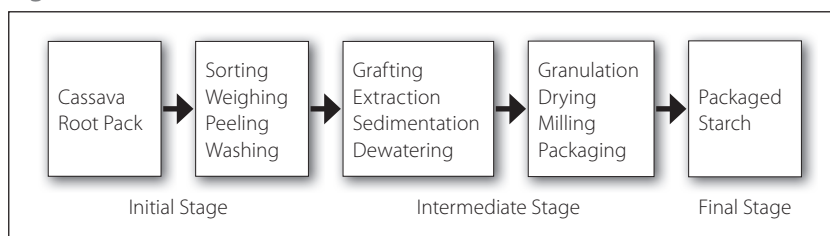
The production processes for cassava flour is as shown in Figure 5. These processes can be grouped into three stages: (a) Initial stage; (b) Intermediate stage; and (c) Final stage.

CASSAVA STARCH

Cassava starch is a whitish, fairly elastic product with moisture content between 8–10 per cent, particle size of 0.2–0.3mm and fibre content of 0.1–0.5 per cent. Unlike some other cassava products, cassava starch is very elastic, very low in fibre content with a very low water absorption capacity (FIRO, 2008). Cassava starch (Figure 6) has wide application in food, pharmaceutical, textile, paper and adhesive industries. The greatest potential of cassava as an agro-industrial crop lies in the production of starch (Ajibola, 1988). The production processes (Figure 7) for cassava starch are: Sorting, Weighing, Peeling, Washing, Grating, Extraction, Sedimentation, Dewatering, Granulation, Drying, Milling, and Packaging.

Figure 6 Cassava Starch

Source <http://www.cassavastarch.org.cn/Images/CassavaStarch.jpg>

Figure 7 Production Processes of Cassava Starch

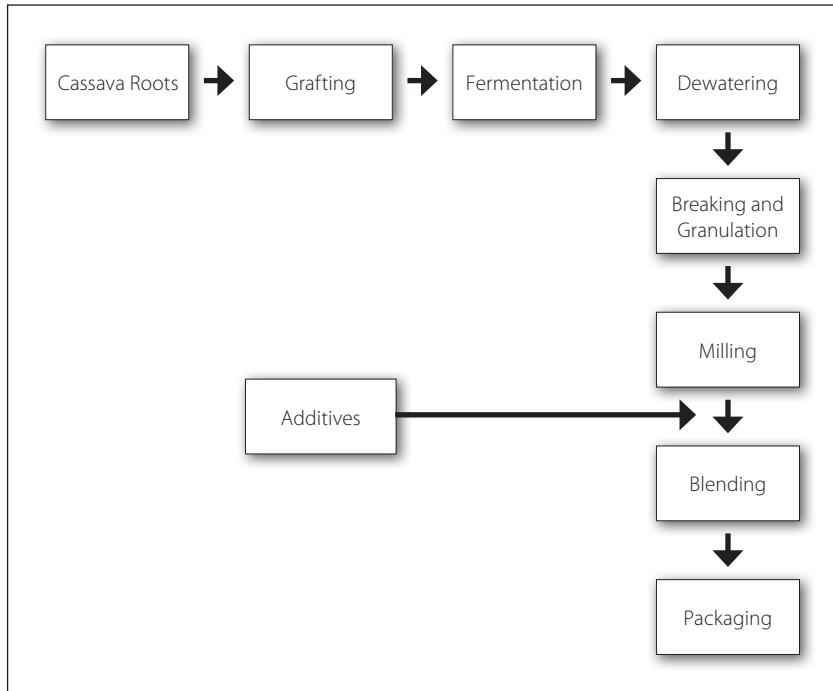
Source Author's own

CASSAVA AND S&T DEVELOPMENTS IN THE POULTRY INDUSTRY

Because of the increase in livestock production in Africa, the requirement for animal feed materials is increasing. The hike in the price of cereals has necessitated the search for alternative sources of energy for animals. The importance of cassava in Nigeria's poultry industry explains why Nigeria has a bigger poultry industry than all other African countries (FAO, 2003). Consumption of poultry meat is also increasing faster than that of other kinds of meat in Nigeria. Feed represents a major proportion of the overall production cost in the poultry and livestock industry in Nigeria (Longe and Adetola, 1983).

Being a cheap carbohydrate source capable of supplying adequate calories, cassava roots offer great potential as an animal feed. Cassava

Figure 8 Production Processes of Cassava Poultry Feed



Source Author's own

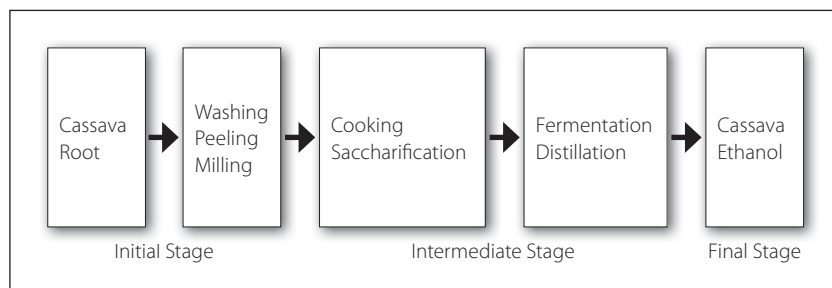
cannot be used as the sole feedstuff because of its deficiency in protein and vitamins. It must be supplemented by other feeds that are rich in these elements (Ajibola, 1988). Moreover, the presence of toxic hydrogen cyanide in cassava is a limiting factor in its use as food for man and livestock. Thus, processing helps to remove or reduce the level of toxic cynogenic glucosides present in the cassava root as well as altering the available energy of the cassava. A modern method of detoxification of cassava for poultry feeds, which is highly mechanised, has been developed at FIIRO. These modern methods are used to detoxify cassava, which can then be used to compound poultry feeds. The detoxified cassava products (whole roots, waste, or peel) have been supplemented with other locally available ingredients and vitamins at FIIRO to provide a complete feed formulation for growing and laying chickens at rates varying from 40 to 50 per cent of the concentrate mixture. The cassava-based grower feed also enhanced growth rate, which was manifested by the rapid gain in weight of the chickens. The feed conversion efficiency of the cassava-based feed was the same as that of the maize-based commercial feed. The cassava-based feed did not have any adverse effect on the livestock. The production technology (Figure 8) of poultry feed from whole cassava roots involve: Grating, Fermentation, Dewatering, Breaking and Granulation, Milling, Additives, Blending and Packaging.

ETHANOL PRODUCTION FROM CASSAVA

The energy crisis has led many countries of the world, particularly Brazil, to investigate the production of alcohol from different sources, cassava being one such raw material (Ajibola, 1988). Cassava starch can be readily converted to ethyl alcohol in a two-stage process involving the hydrolysis of starch slurry into glucose. The glucose solution is then diluted and converted to ethyl alcohol by the anaerobic action of yeast. Ethanol is a clear volatile colourless and flammable liquid which burns with a blue smokeless flame. The basic technology involves washing, peeling, milling, cooking, saccharification, fermentation and distillation (Figure 9).

The ethanol derived from the process is known to be of high quality similar to cereal alcohol and can find applications other than for fuel.

Figure 9 Production Technology of Cassava Ethanol



CONSTRAINTS FACING THE CASSAVA SUB-SECTOR IN NIGERIA

Cassava tubers consist of 60 to 70 per cent water and have a shelf life of two to three days. Once harvested, the tubers have to be processed or consumed immediately otherwise the tubers begin to deteriorate. The need for processing is to stabilise the crop for storage purposes and price stability guaranteeing higher prices for farmers. The need for innovative cassava processing technologies is enormous. Traditional cassava processing has a number of undesirable attributes. It is time and energy consuming, provides low yields and lacks storage capacities. However, the cost of acquiring simple processing machines is prohibitive for the small scale farmer and in the more humid cassava producing areas, the use of dryers is critical. There is also a need to ascertain accurately the effect of processing costs on the final price of the cassava products. Against this background, the challenge for cassava industrialisation lies with the reduction in the cost of production and transformation to enable the supply of cheaper processed products of desired quality and standards to markets, including potential agro industries.

In order to gain real benefits from using improved technologies, effective linkages are essential between processors and markets. However, such linkages do not always exist, particularly in remote areas. Farmers have not always been able to set up linkages themselves and may need assistance. According to Westby (2002), SMEs can play important roles in market chains by providing access to capital, processing facilities and commercial transport, relevant manufacturing experience, proven business record, proven record on quality, an understanding of marketing issues, and a willingness to support farmers and processors for mutual gain. Quality standard marks may also be used by enterprises in marketing in order to promote appropriate approaches to quality assurance through ratification of quality standards to protect consumers and assure them of the quality of products.

The key role of the public sector in supporting the private sector include the documentation and promotion of best practices and approaches to commercialisation; providing information on post-harvest technologies and how to access them; supporting access to market information (at various levels) and guidance on how to access market information; support to preparation of business plans; support to development of regional and national strategies to commercialise cassava; facilitating access to technical support for micro, small and medium scale enterprises and equipment manufacturers; policy guidance in support of commercialisation and support to development and application of food standards for cassava products combined with guidance concerning labelling. The financial returns of investments in the cassava sub sector will depend on specific products being prepared and the market being accessed. At the simplest level, improvements in fresh cassava marketing systems can increase profits by 16 per cent for certain members of the marketing chain. The adoption of cassava chip processing as an alternative to marketing fresh chips increased profitability for farmers in coastal Tanzania by 290 per cent. These figures give an indication of the potential benefits that can be achieved by investing in additional value at the rural level. To date, few cassava farmers, processors and traders (exemplified by the UNDP/Obafemi Awolowo University, Ile-Ife, Nigeria and Osun State Agricultural Project) have received support in Nigeria. Efficiencies may be gained in providing backstopping support through a coordination unit. The emphasis of the intervention is mainly in terms of soft infrastructure to support private sector involvement in the commodity.

Losses occur in all operations from harvesting through handling, storage, processing and marketing. They vary according to the influence of factors such as the perishability of the commodity; ambient temperature and relative humidity which determine the natural course of decay; fungal and bacterial decay; damage by pests (insects, rodents and birds); the length of

time between harvesting and consumption; and practices of post-harvest handling, storage and processing. Most post-harvest handling, processing and marketing systems in Nigeria also operate at a rudimentary level and present few opportunities for farmers, processors and traders. Post-harvest handling of cassava is the largest constraint to increasing cassava production in Nigeria. Most often, post-harvest losses are a symptom rather than the problem. Knowledge of their cause is therefore, essential for deciding measures to prevent them. Such measures may have to be taken by the small farmer, the private trader, a cooperative, the marketing board or other operator, handlers and transporters, wholesale and retail markets.

A study by the International Food Policy Research Institute on the impact of post-harvest research by the Consultative Group on International Agricultural Research (CGIAR) on food security, poverty alleviation, and sustainable agriculture in developing countries, has identified four major trends within the global food system that are making post harvest activities increasingly important in terms of economic returns and nutrition. Urbanisation, changes in the agricultural sector, market liberalisation and shifting market options as well as improvements in infrastructure and communications were identified as areas of impact that justify increased funding for post-harvest research and development. The rapid rate of urbanisation, particularly in developing countries, is causing major changes in the food system. As people live farther away from where food is prepared, they rely increasingly on rapid reliable transport, storage, processing and marketing systems to give them access to a secure food supply. The reduced time available for food preparation and increased demand for processed food also increases the need to develop healthy, affordable food products and appropriate processing systems to feed the growing urban populations. There is change taking place in the agricultural sector. What is notable in this change is the contraction of the sector in terms of a declining agricultural GDP as a share of total GDP and a declining labour force engaged in agriculture. Alternative rural income sources are essential to limit rural-urban migration and this need is acute in many developing countries where industrial employment is not sufficient to absorb the influx. Post-harvest activities such as processing and marketing can provide much needed employment for those who exit the agricultural sector. Research on policies, institutions, and technologies to strengthen the development of rural agro-enterprises directly contributes to the strengthening of the rural economy even within a contracting agricultural sector. Participation in international markets demands relatively sophisticated marketing, information and transportation networks.

Thus, the more liberalised international trade system and an increasing orientation of developing countries towards export markets as a source of

economic growth requires new skills and structures within the existing agricultural sectors. Successful competition needs quality control and product standardisation. While large companies are economically able to develop sophisticated marketing strategies, smaller producers will greatly benefit from methods and technologies that allow them to compete in international markets. Developing a strategy that will contribute to food security and socio-economic growth and development would entail the existence of a growing demand (market) for cassava. This can occur when its unique characteristics are exploited in a specific end use market, or if cassava becomes economically more attractive for a particular use than do competing products. An immediate concern would be to identify and analyse the current uses and the potential markets for cassava and its products.

CONCLUSIONS AND POLICY RECOMMENDATIONS

Enhancing the value of cassava in Nigeria poses different challenges to the political leaders and policy makers and to cassava researchers and producers. Modern S&T remains one of the key factors that can determine the sustainability of Nigeria's global leadership in cassava production. This is likely to be successful, only if supported by appropriate policies and institutions. Modern S&T is only one of many factors that will determine whether and to what extent the poor farmers will benefit from or lose for integrating into the exchange economy. Thus, S&T must be guided to benefit Nigerian farmers and to address the issue of food security in the country. There is need for the government to encourage private sectors to make necessary investments in developing technologies for expanded use of cassava as raw material in food, non-food and animal feed. They could be used by agro-industries to produce other products like starch, dextrin/adhesives, flour, ethanol for the other industrial (e.g. textiles, paper, wood, etc) and consumer (food and beverage) markets. Unfortunately, no supply chain structures exist for the commercialisation of secondary cassava products as source or raw materials for agro industries. Current post-harvest development activities on cassava roots and products show the same deficiencies as disciplinary and commodity-oriented approaches in agricultural production (Dada *et al.*, 2007). Researchers and extension workers strive to minimise food losses in their technical discipline, but activities are isolated.

From the foregoing, post-harvest research has made significant contributions to developmental goals, such as poverty reduction, food security and sustainability. The economic analysis of post-harvest projects also reveals that it is associated with a high rate of return which requires more funding. It is therefore important to seriously reexamine current funding of

research priorities and to allocate a larger proportion of resources to post-harvest research. However, it is important to note that many improved agricultural technologies fail to gain widespread adoption because the research which developed the technology was neither market-driven nor suited to the economic framework of the target group. To improve the market options for cassava and cassava products, there is need to shift strategy from production to the needs of the local market. Thus, the whole chain between production and consumption should be reassessed holistically. Preservation technologies should be evaluated for their ability to keep cassava products over an extended period of time. Quality of the product should be monitored at regular intervals. Processing equipment and other technologies should be introduced and tested on pilot basis and socio-economic factors affecting adoption should be studied. Demonstration through group training at pilot resource centers in order to create awareness of utilisation potential. National post-harvest programmes should be encouraged to boost the variety development efforts in the determination of cyanogenic potential, starch yield and quality, dry matter content, cooking characteristics and suitability of varieties for dominant food and product preparations within the region. Household incomes can be increased by overcoming post-production constraints, e.g., by improving access to markets, by reducing losses in the market chain, by adopting better on-farm storage and by adding value to raw food commodities. Investment in post-harvest systems is also essential in order to maximise benefits gained from improvement in crop yields and from better pre-harvest pest and disease management, while taking systems-based approaches to post-production challenges, involving private sector partners along the entire market chain, as well as working with a wide range of public- and private-sector service providers is imperative.

Access to improved cassava processing technology at any processing stage would reduce processing labour and would lead, not only to an increased level of processing but also to increased production since labour released could be channelled into production activities. It would also improve product quality. Improved quality would make the product attractive to urban consumers, thereby expanding the market for the product. This would provide an incentive for expanded production. As most processing labour is provided by women, mechanisation or use of improved technology for the frying activity should be obtained through rural savings and other sources of funds organised by women.

There is need for the government to encourage private sectors, for instance with intellectual property right protection, to further make the necessary investments in developing technologies for expanded use of cassava as raw material in the food, non-food industries and livestock feed industry. Government and agricultural machinery companies should give

the requisite assistance towards the commercialisation of viable cassava processing machinery emanating from research institutions, which if mass produced will be available to the processors at subsidised rate. This can however, be achieved by effective management of technology through the use of appropriate policies to fully reap the benefits deliverable from cassava. The development of the cassava sector requires initial activities in capacity building, product development, fabrication and transfer of processing technologies to target beneficiaries and development of clusters to supply identified markets (Dada *et al.*, 2007), hence, the need to map out the cassava value chain and innovation systems in Nigeria. This is imperative to the sustainability of the cassava sectoral innovation system, with a view to facilitating the link between the supply and demand in the most effective way through information sharing.

Improving agriculture from its abysmal low level of yields and poor quality products to commercial and beneficial levels could only be achieved through the dissemination, application and utilisation of up-to-date knowledge and information on modern techniques and technologies of practicing agriculture.

Consequently, future intervention strategies should include the following: Deliberate efforts to support the development of cassava processing prototypes and identification of applicable and useful technologies and incentives for local entrepreneurs to fabricate them. This will save labour and improve the efficiency of processing, raise the quality and enhance marketability of products. Development of new cassava products and packaging techniques for existing and new products; promotion of industrial uses of cassava and diversification of processing options to encourage increased cassava production and enhance rural household income; establishment of a sound macroeconomic policy that will promote sustained cassava development; greater involvement of the private sector and non-governmental organisations in the use of research and technology in cassava production, processing and marketing and in the development of infrastructural facilities.

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Enhancing Innovation in Developing Country Systems

A Synthesis of Case Studies and Lessons from Uganda*

Kiggundu Rose

SUMMARY

A contribution to an improved empirical understanding of the nature of innovation system competence building in Africa is made. First: A framework of analysis for assessing system competence building is defined and applied to five case studies drawn from Uganda. Second: Drawing from the case studies three appreciative empirically grounded system building typologies is identified. We found the most common type continues to be that organised to introduce new knowledge and innovation and strengthen research and technology systems. Other kinds of system building have received far less attention. A comparative analysis of case studies reveals important sectoral and spatial specificities which help to explain why within a national system of innovation, the same approach successfully employed to build competences in one specific sector or geographical location may not have the same effect elsewhere. There is still a long way to go before all relevant actors acquire a full understanding of what it would take to build functional systems of innovation and the competences required.

INTRODUCTION

It is widely acknowledged that innovation is an important driver of growth and development. The question is why and how innovation occurs and therefore how best to promote it. Especially since the 1980s, many have underlined the usefulness of conceptualising and pursuing this task from a systems view of innovation; also usually referred to as innovation systems view.

Innovation systems work through the introduction of knowledge into the economy (and into the society at large). It requires active learning by

individuals and organisations taking part in processes of innovation of different kinds. The efficiency of these learning activities, and hence, the performance of innovation systems depends on economic, political and social infrastructures and institutions (understood as habits, norms and values). It also depends on past experiences as they are reflected in the tangible and intangible aspects of the structure of production and on values and policies (Lundvall *et al.*, 2002: 225-226).

Scholars have however cautioned that a 'broad' conceptualisation is more useful as "a narrow innovation system concept focusing [mostly] on research and development system and on high-tech and science-based innovations makes [...] less sense in the South..." further emphasising that "...when applied to the South the focus ought to be shifted in the direction of innovation system construction and system promotion" (Lundvall *et al.*, 2002: 226). In the case of Africa, some suggest that 'competence building' (Lundvall *et al.*, 2002) not only has to take centre stage but also be done in a manner cognisant of the wide set of issues that are relevant for building African systems of innovation (Muchie *et al.*, 2003).

The problem, however, is that because several people in research, policy and development are still locked into old traditions and longstanding ways of promoting innovation, there is still insufficient understanding and a great deal of confusion as to what you actually do and abandon in order to bring an innovation systems view into play. In the context of the South, the literature still has very few examples of how you apply the 'broad' innovation systems concept not only 'ex-post' for explaining the emergence of systems but also 'ex-ante' (Arocena and Sutz, 2000) for 'system building'.

This paper seeks to contribute to the suggested focus on learning and system building in the South and particularly in Africa, by addressing the following three inter-related questions:

1. What is the nature of learning and innovation competence building initiatives commonly implemented in Africa?
2. Why do some initiatives in the same '*national system of innovation*' tend to achieve much greater success than others in unleashing learning and innovation?
3. What are the key generalisable findings and lessons that could allow actors in policy, research and development to improve their understanding of 'How To' and 'How Not To' promote learning and innovation?

The paper is organised into four sections. Following this introductory section, the analytical framework, associated literature and methodology are discussed in Section 2. Case studies are discussed in Section 3, while

Section 4 provides a comparative analysis, some concluding observations and policy inferences.

THEORETICAL BACKGROUND AND ANALYTICAL FRAMEWORK

In this paper, as in Ernst *et al.*, (1998) and in Mytelka (2000), whenever the term innovation is used in the sense of a process, it refers to the creation, diffusion, mastery and productive use of new or already existing ideas and knowledge in the economy irrespective of whether or not these new ideas or knowledge are new elsewhere. Various types of knowledge are relevant; scientific, organisational, entrepreneurial, marketing and farm or establishment-level knowledge, the latter often 'tacit' (Polanyi, 1967), that is, un-stated, hidden in daily routines and difficult to transfer. Innovations can take the form of new production processes, new products, new forms of organisation and new markets; new to the establishment or country. Innovation does not refer to technologies or to inventions, and studies emphasise that it is simply not enough to produce good science and technologies if they cannot be 'translated' into uses of benefit to farmers, firms and economies (Lundvall, 1992; Edquist, 1997).

In an open economy, 'not to innovate' means that domestic producers will bear the negative impact of innovations made by others. Domestic producers are constantly confronted with competition from innovating producers abroad. This is also true for countries producing agricultural products for the world markets—there is a permanent drive toward more attractive and cheap products also in this field. Therefore, in most markets, not to innovate means continuously to lose market share and income...(Lundvall et al., 2003: 2-3).

The more contemporary view of innovation elaborated for example in Freeman (1988), Lundvall (1992) and World Bank (2006a), also recapitulated in Table 1, emphasises that innovation derives from a much broader and interactive process involving the whole system of innovation.

The latter defined as a network of organisations, enterprises and individuals focused on bringing new products, new processes, and new forms of organisation into economic use, together with the habits, norms and values, policies, linkages, political, historical and economic context that affect their behaviour and performance.

In Edquist (1997), we are reminded of the origins of the expression 'systems of innovation' whose beginnings are traced to the term 'national systems of innovation' (NSI) developed by Freeman (1987, 1988); Lundvall (1988, 1992) and later, other scholars. Related literature has since evolved

Table 1 Distinction between the Old and Contemporary View of Innovation

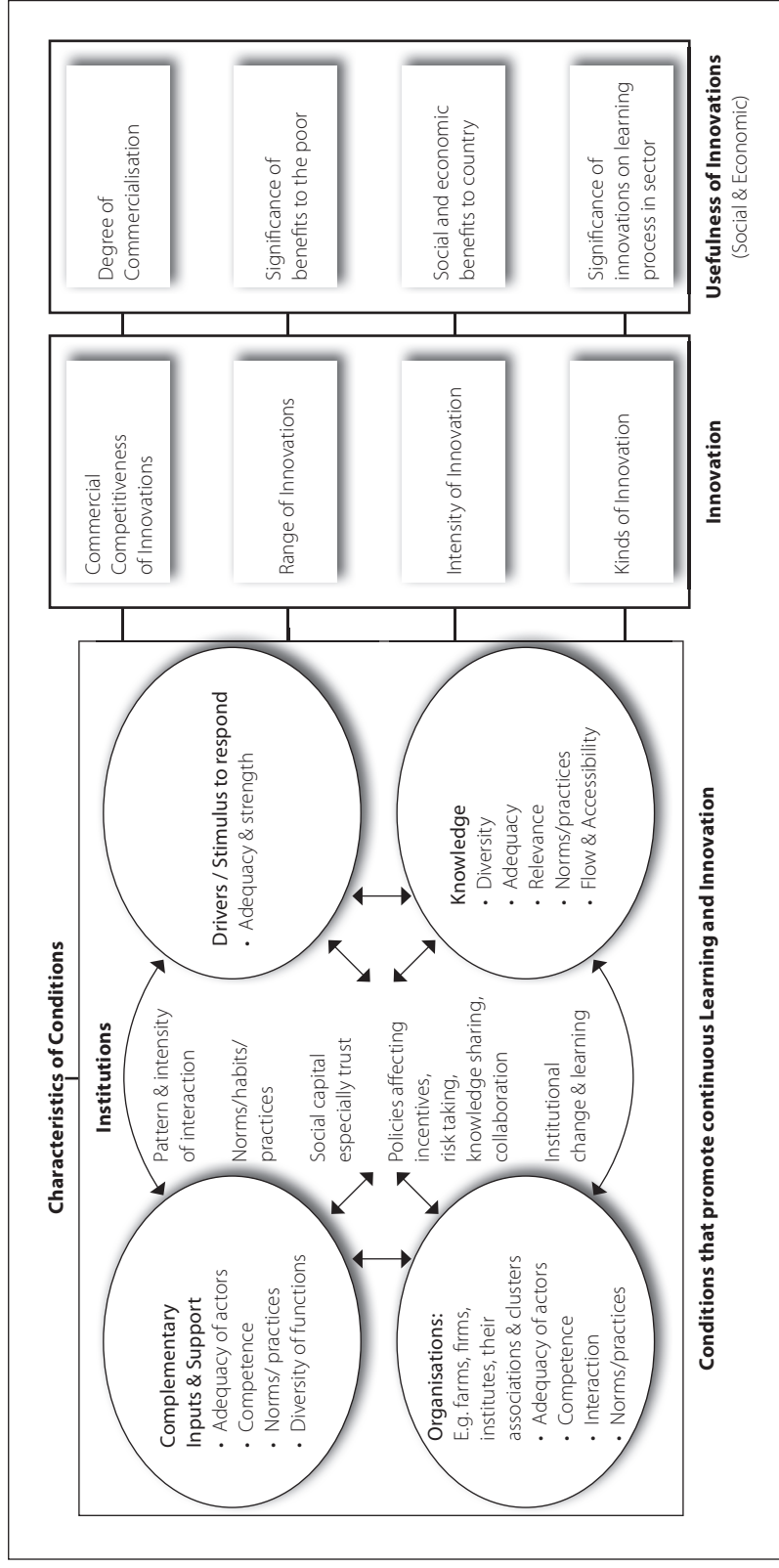
The Old View and Interpretation	The Contemporary View
Technology policy largely based on linear model of innovation: Science push/ market-pull	Focus is on knowledge creation and utilisation; notion of innovation
Simplistic: Scientific research would create a basis for new technologies which if transformed into new products would bring about strong economic growth	The process of putting knowledge into use is complex and unpredictable
Hence the focus mostly on research and development, science-based innovations, technology creation and neglect of broader environment within which innovation occurs	Different types of knowledge (managerial, scientific, informal, institutional, service delivery, organisational, etc) have to be combined for innovation
Many African countries wrongly believed technology would be transferred from the industrialised world or from science-based organisations to users without deliberate and parallel local efforts to invest in domestic technological and innovation capability development	Innovations are influenced by many players, organisations and their behaviours: policies, routines, traditions and practices (the institutional setting)
Underlying assumption that knowledge was easily transferable and integrated into existing social, economic and technical practices	The institutional setting can promote and retard innovation
Linkages confined to traditional partners to deliver and scale out technologies	The nature of demand matters
A competence building agenda focused on enhancing scientific capacities and adaptation of technologies	Complementary support and services are essential
In agriculture, successive conceptual and operational frameworks still failed to turn technologies into social and economic prosperity for the poor	The interaction of the entire system of organisations, institutions (policies, norms) and social, political and economic contexts affects knowledge flows and its integration in social and technical practices
In industry, dynamic domestic technological capabilities and innovations of economic significance generally failed to emerge	Shift of emphasis from mostly research and development, knowledge and technology generation, to learning and innovation competence building conceived in a much broader and holistic sense

Source Compiled by the author from innovation systems literature

into various territorial and other variants. In this paper, the focus is on the 'national' dimension and within it, on a number of 'sector-based' (Mytelka, 2003) and 'product-related' systems of innovation (World Bank, 2006a).

In practice, we can think of a system as an interconnected set of components that collectively contribute to the functioning of the whole. A system consists of interlinked subsystems and because there is interdependence in a system, a system is more than the sum of its subsystems.

Figure 1 Innovation System Competence Building – Framework of Analysis



To assess system competence, the literature points to a number of analytical elements which we can classify into the following broad categories:¹

1. Nature of drivers of change in the system;
2. Actors or players in a particular system or subsystem, their functions and competences;
3. Underlying 'institutional' context in the sense of: (a) Policies and competences for developing and implementing policy; (b) Traditional attitudes, mindsets and ways of doing things; (c) Patterns of linkages, relationships and interaction;
4. Knowledge (different types);
5. Complementary inputs, services and support structure;
6. Characteristics of innovations that 1) to 5) lead to.

In our case study analysis, the key task is to assess how well these broad elements of competence (building) co-existed, functioned and interacted to enable or hold back learning and innovation in a developing country setting (See Figure 1).

METHODOLOGY

To address the research questions previously outlined, five key tasks were undertaken:

1. Background review of secondary material to identify recent examples of learning and innovation initiatives undertaken in developing countries. For ease of interpretation and comparison, we focused on initiatives only in one region (Africa), and only in one developing country (Uganda);
2. Developed analytical framework;
3. Gathering of primary information from key informants that included researchers, past and current staff directly affiliated to the initiative, staff at government ministries and partner private organisations, NGOs, other public sector officials and consultants familiar with the initiative;
4. Applied analytical framework to five case studies; analysed case studies in a comparative way and reported key findings in terms of:
 - characterisation of innovations
 - circumstances and factors underlying performance; and
5. Based on individual case study analysis and the comparative review, identified some conclusions, general lessons and a few guiding principles for *innovation competence building*.

CASE STUDY SELECTION AND ANALYSIS

In recent contributions, World Bank (2006a) and Larsen *et al.*, (2009) discuss some interesting examples of learning and innovation in Africa. In this paper, our focus is on system building in Africa and on examples that enhance our understanding of this process. We chose Uganda for this research because of the remarkable changes and economic progress reported there since the 1990s (Bigsten and Kayizzi-Mugerwa, 1999, Reinikka and Svensson, 1999, Kasekende and Ssemogerere, 1994, Holmgren *et al.*, 2001). By comparison to other African developing countries, Uganda was expected to have a much improved enabling environment and support system for learning and innovation.

Once the country of focus was chosen, we were interested in examples of initiatives undertaken in the agricultural and agro-industry sectors since many African countries are still largely reliant on agriculture and on agro-based industry. Across these sectors, we identified at least three possible broad categories or types of system building from which we could select case studies. The three categories are:

1. **Type I** – System building to introduce new technology and/or applications in a new context
 - Strengthening of research and technology generation systems
 - The push for adoption and use of new or validated technology [Case studies 1, 2, 4 & 5]
2. **Type II** – System building based on shift in paradigm, priorities, policy and/or regulation
 - New thinking and approaches leaning more towards integration of economic and technological capability development [Case study 3]
 - Self engineered and/or globally dictated changes in policy direction, e.g.
 - Self-created competitive advantage in traditional sectors
 - High-tech exports and new niche sectors
 - Export diversification [Case studies 3 & 4]
 - Increase of local content/reduction of import intensity in production
 - Competition policy
 - Procurement policy
 - Self-organising and/or orchestrated response to demands of high-margin markets [Case study 3]
3. **Type III** – System building to respond to changes and crises in market dynamics [Case study 3]

- Opportunity to enhance emerging pattern of integration of a sector or product line in new markets
- Opportunity for new value-adding activity in existing or new value chains
- Opportunity to enhance emerging pattern of new value-chain organisational arrangements across a sector or product line

We were unable to obtain information representative of all the different types of system building pursued since the 1990s. Case study sample selection was therefore not based on considerations of representativeness or maximum variation. Instead, we considered the information available and then purposively selected five case studies to capture variety in types of recent system building efforts. For ease of reference, we will refer to the three identified categories of system building as Type I, Type II and Type III.

Table 2 introduces the five case studies selected for research. All case studies are drawn from initiatives implemented in Uganda since the 1990s and from research visits, observation and field interviews undertaken by the author in Uganda in different periods between 2002 and 2005.

The work reported in this paper is a preliminary attempt to examine and learn from relatively recent 'system building' initiatives in Africa. Bearing in mind the obvious limitations of country and sector specificity, findings from our research should bear relevance to varying degrees to many innovation competence building efforts in comparable developing countries.

CASE STUDIES

CASE STUDY 1:

THE PUSH-PULL PROJECT IN BUGIRI DISTRICT – UGANDA

In the late 1990s and early 2000s, research conducted in Eastern Uganda by the local National Agricultural Research Organisation (NARO) reported that a parasitic weed known as striga (*Striga hermonthica*) was having devastating effects on maize, rice, sorghum and millet production. Drawing from the widely documented pest management 'push-pull' technology (Khan *et al.*, 2000; Hassanali *et al.*, 2008), a push-pull initiative was introduced in Eastern Uganda to simultaneously address three of several problems that farmers faced: Striga, stem borers and soil infertility.

The 'push-pull' strategy combines a 'push-pull' tactic for controlling stem borers on one hand, and an in situ suppression and elimination of *Striga hermonthica* in maize-based farming systems. The strategy involves trapping pests on highly susceptible trap plants (pull) and driving them

Table 2 Criteria for Case Study Selection

Case Studies	Types of System Building		
	Type I: Strengthening of public research systems; Introduction of technology or applications in a new context	Type II: Shift in thinking, policies and/ or regulation; integration of technological & economic capability development	Type III: Response to changing dynamics & crisis in value chains and markets
Case Study 1: Push-Pull Technology Initiative for pest management in Bugiri	✓		
Case Study 2: Livestock Systems Research Initiative in Masaka	✓	✓ (partly)	
Case Study 3: Response to export market requirements in the Fisheries and, in the Fruit and Vegetable (F&V) sector		✓	✓
Case Study 4: New ways of managing the Apple Banana	✓		✓ (partly)
Case Study 5: New potato variety and new joint ways of working	✓	✓	

away from the crop using a repellent intercrop (push). Plants that have been identified as effective in 'push-pull' tactics include Napier grass (*Pennisetum purpureum*), Sudan grass (*Sorghum vulgare sudanense*), molasses grass (*Melinis minutiflora*), silverleaf desmodium (*Desmodium uncinatum*) and greenleaf desmodium (*D. intortum*). These plants are of economic importance to farmers in eastern Africa as livestock fodder and have shown great potential in stemborer and striga management in farmer participatory on-farm trials. The innovations have found ready acceptance among the small-scale and medium-scale farmers in East Africa (International Centre of Insect Physiology and Ecology (ICIPE) in FAO, 2002: 7-8).

Activities guided farmers to intercrop elephant grass, desmodium legumes and maize. Scientists from ICIPE and the local national research

system (NARO) worked with international and regional development agencies, the agricultural extension system, some non-governmental organisations (NGOs) and farming communities to diffuse and ensure the use of the technology. Adoption was slow however and somewhat disappointing hence the multi-faceted effort launched in 2006, to accelerate the adoption, dissemination and “expansion of the push-pull technology in eastern Africa from previous 12,000 to more than 40,000 farm families by the end of 2009” (ICIPE, 2009). The jury is certainly still out on how this more recent initiative (2006–2009) has worked to learn from previous periods of technology dissemination and utilisation. Our focus is on activities in the period immediately preceding the 2006–2009 effort.

Although push-pull activities were introduced almost in the same period (early 2000s) to several districts of Eastern Uganda namely Bugiri, Tororo, Kapchorwa, Busia and, later (2004) Pallisa district, researchers reported that adopters were mostly concentrated in Bugiri district and in Nabukalu sub-county in particular. Beyond the 50 farmers for whom the technology was initially demonstrated, an additional 160 farmers had already adopted the intercropping practice by the end of 2005. Adopters had also created a savings and credit cooperative through which they pooled and collectively marketed their agricultural produce.

In other words, when a pest management technology was introduced it was supported by complementary organisational arrangements and services that enabled smallholders to make productive use of the technology. With time, maize yield increased and the introduction of new ways of marketing enabled farmers to extract more social and economic value from their produce. This incremental innovation process in Bugiri did not occur to the extent it could in neighbouring districts and the question is why?

In Bugiri, activities were implemented in partnership with the NGO known as FIFOLA whose leader provided tremendous entrepreneurial, technical and organisational oversight. The NGO leader held a Bachelor of Science degree in agriculture and observers mentioned he portrayed characteristics and behaviour of a highly self-driven and visionary leader (Field interviews, Bugiri district, 2005). FIFOLA linked the crop intercropping initiative to a heifer scheme which it helped create with support from donor agencies. The idea was to incorporate an incentive regime that would reward the best performing 20–30 crop inter-croppers (farmers) with a local heifer. The NGO trained farmers and provided information on the benefits of controlling striga. It boosted awareness of the multi-purpose role played by desmodium. It provided technical assistance to participating farmers and regularly supervised the management of fields (Author's interviews, 2005).

Clearly, one of the reasons the scheme worked relatively better in Bugiri district is that the partner NGO had an educated, entrepreneurial champion

running the intervention and he did not run it elsewhere. But if such leadership and other required capabilities were missing in the other districts, why did the promoters of the initiative not invest in the development of linkages to this particular NGO (FIFOLA)? The need for such action seems obvious but as is often the case, the promoters of new technology were not very attentive to the non-technological aspects often critical for enabling technologies to be widely and productively used. In this particular case study, too little attention was paid to the building of linkages and mechanisms for enabling already available leadership, organisational and marketing knowledge especially the tacit aspects to flow and be used elsewhere. As we shall see in the next case study, this situation is common and not peculiar to Eastern Uganda or to the push-pull activities discussed here.

CASE STUDY 2:

THE LSRP INITIATIVE IN MASAKA DISTRICT – UGANDA

The “Livestock Systems Research Programme” (LSRP) traces its roots to a district diagnostic survey conducted in 1999 which identified feed inadequacies across smallholders in Masaka district. In response, LSRP was started in the year 2000 as one of seven components of the “Agricultural Sector Programme Support” (ASPS) funded by DANIDA, the international development agency of Denmark. The implementation of ASPS was led by Uganda’s Ministry of Agriculture, Animal Industry and Fisheries (MAAIF). LSRP was included in the first phase of ASPS and was coordinated by Namulonge Agricultural and Animal Production Institute (NAARI), one of several institutes under the National Agricultural Research Organisation (NARO).

The LSRP brought together a ‘cross-disciplinary’ team (Aargaard-Hansen *et al.*, 2007) of agronomists and livestock specialists to conduct farm-based research in free-range poultry, smallholder dairy cattle farming, pastoral and agro-pastoral farming systems, small ruminants and diagnostic tools. The research initiative was made operational in six districts representing different ecological conditions and livestock farming systems. It created several partnerships with Makerere University (for example) and was implemented through a number of NARO’s research institutes at Serere, Tororo, Namalere and Namulonge (ASPS Bulletin, 2002).

In Masaka district, the focus was on smallholder dairy farming. LSRP promoted stall-fed smallholder dairying activities and worked to convert them into a profitable and commercial business. It tested various fodder options, identified problems hindering adoption, and assessed the economic viability of a number of fodder bank technologies. It also supervised and facilitated research work for several graduate students that were attached to the activities in Masaka.

Reports indicated that milk production increased, knowledge among farmers increased (e.g. record keeping and management) and there was more interaction between farmers, extension officers and researchers as well as among farmers themselves (Mubiru *et al.*, 2002, Laker and Bashasha, 2004). Labour was saved by reducing the time previously spent hunting for fodder. The manual preparation of grass hays was too labour demanding and did not work well. The intercropping of lablab forage species with maize was the most acceptable option. However, farmers still faced second generation difficulties such as fodder transportation from the fields, the drudgery of working with manual fodder chopping equipment, free-grazing animals that encroached on farmers' fodder banks and other problems.

A new follow-on project supported through the regional animal research network, ASARECA, was introduced in 2006 to test innovative approaches towards feed conservation technologies. As of 2007, activities included the testing of a mobile, commercially run and motorised fodder-chopping service operated by a youth group from a local vocational institute (Author's interviews, December 2007). The goal was to respond to labour constraints of the farmer by initiating a door-to-door commercial fodder-chopping service for the preferred/adopted fodder option and to create new jobs at the same time. Linkages were created with members of local organisations such as Masaka Diocese Development Organisation to test some of these ideas and to tap into a potential market for milk and hay.

The work done in Masaka district and the lessons accumulated there were indeed very valuable and potentially beneficial to many other initiatives and other smallholders working in more or less a similar setting. LSRP also operated in Mbale district, a milk-deficient area and similarly smallholder dominated area. Although Mbale is located in a different geographical area and the farming system there is different, we did not find any evidence to suggest that organisational and generic system building lessons from LSRP's past and ongoing work in Masaka and positive results from earlier research were being applied to Mbale's context for example. There seemed to be very limited spatial flow of knowledge and lesson diffusion as of the time we conducted follow-on phone interviews in 2007 and 2008.

CASE STUDY 3:

STANDARDS AND INNOVATION: UGANDA'S FISHERIES AND THE FRUIT & VEGETABLE (F&V) SECTOR COMPARED

The prudent enforcement of standards can stimulate innovation especially in a developing country setting (Kiggundu, 2006a). In the case of Uganda,

the imposition of stringent standards on fish imports into the European Union (EU) and the export crisis that followed (1997–2000) galvanised the emergence of a more effective support system in Uganda's fisheries sector.² A wide range of actors responded in various ways, new collaborative relationships facilitated useful flows of knowledge and services and Uganda's fish exporting sector successfully engaged in learning and innovation activities, changes that resulted in substantial gains for Uganda's economy (Kiggundu, 2006b). However, the conditions and processes underlying this success and associated key lessons have not been easy to recreate and adapt in other local sectors facing more or less similar circumstances. For instance, even though Uganda's response to the EurepGAP³ standard in the F&V sector was modelled along the lines of response undertaken in the fisheries sector, the effect on the economy and on learning and innovation in the F&V sector was far less significant.

EurepGAP is a private standard initiated by large supermarket retailers in Europe. Specifications can vary by supermarket and exporters are certified EurepGAP compliant if they fulfil a wide ranging set of requirements including traceability, soil management, fertilizer use, irrigation, crop protection, waste and pollution management and others. Since its effective date in January 2005, access to mainstream F&V markets (supermarkets) is largely dependent on compliance with this private protocol (World Bank, 2006b).

As with the fisheries sector, the introduction of EurepGAP meant that access to high-margin mainstream (super) markets was conditional upon full compliance with stipulated requirements. In response, the government of Uganda established a taskforce and EUREPGAP secretariat at the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) and allocated a budget towards EurepGAP compliance. The response involved a diverse set of actors. The taskforce was led by government officials and it included representatives of MAAIF, exporting companies, the horticulture unit at Kawanda Agricultural Research Institute (KARI), chemical suppliers, exporters and the Uganda National Bureau of Standards (UNBS). Agribusiness Management Associates (AMA), a private consulting firm served as secretary to the secretariat. Besides a coordinating taskforce, a pool of experts was mobilised. It included local and international specialist organisations as well as regional experts and organisations from neighbouring countries such as Kenya (Author's Interviews, 2005).

This effort did not however bring about the kind of learning, innovation and export success as that observed in the fish export sector. This is attributed to a number of factors including export non-competitiveness and standards non-compliance (Vette and Sergeant, 2004, Gabre-Madhin and Vette, 2003, World Bank, 2006b).

In general, the F&V sector acquired only very limited capabilities relative to what it would take to effectively comply with EurepGAP. The sector lacked effective leadership and the initiative did not benefit from the kind of national political good will that the fish export sector had managed to attract. Collective effort, coordination and infrastructure were all weak. The sector was dominated by low input, low output smallholders, small scale farm suppliers and small-sized companies dealing in domestic and export trade. It benefited from the entry of large commercial farms and their new export supply partnerships. It also benefited from the establishment of local branches by foreign-owned large supermarkets (Bear and Goldman, 2005, Ribbink, Nyabuntu and Kumar, 2005). However, as of 2008, it still lacked complementary policies, linkages, technological partnerships (local and international), infrastructure and support systems necessary to tap into and leverage technologies across the emerging pattern of supply chain organisational arrangements. Without a much broader strategy to tackle sectoral specificities and difference in structure, we were not surprised to find that the effort to deal with export market requirements along lines of response similar to those earlier introduced in the fish exporting sector had achieved much less success in Uganda's F&V sector.

CASE STUDY 4:

PROMOTING INNOVATION ON AN INDIVIDUAL BASIS – BUNCH

SLEEVEING OF UGANDA'S APPLE BANANA

This case study will present some analysis of what happened when Kawanda Agricultural Research Institute in Uganda (KARI),⁴ a local public research institute and a related local research institute worked mostly alone to experiment with a new post-harvest technology to manage and market Uganda's apple banana. The experiment was part of a broader initiative supported by The UK Department for International Development (DFID).

Uganda has a long tradition of producing apple banana especially in Bushenyi, Mbarara and Masaka districts in the Western region, and in Mbale and Mpigi in the Eastern and Central regions. The post-harvest intervention was partly inspired by the perception that the apple banana had export potential especially if solutions could be found to enhance its quality and to control a devastating and widespread disease; the banana wilt. Prior to the intervention, scientists at Kabanyolo agricultural research centre had invested in years of tissue culture and succeeded in developing disease free planting material (Hall and Dijkman, 2006). In the collaborative effort that evolved, Kabanyolo supplied planting material while KARI promoted new improved post-harvest handling techniques. The aim of the post-harvest

initiative was to enhance the quality, yield and marketing system of fresh and solar dried apple bananas (Agona *et al.*, 2002).

In the case of the apple banana marketed in fresh form, the main issue was the failure to consistently meet market requirements and preserve freshness of the banana especially that destined to high premium markets. While buyers demanded bananas of the same maturity without bruises, some were supplied before ripening, some were over ripe and the other half ripe. The project intervened by promoting a simple technique named bunch sleeving. Scientists procured and distributed polythene bags from a local manufacturer. These were to be used after the bracts had fallen and fingers were fully opened. The idea behind bunch sleeving was to avoid bruising by bagging or covering the bunch with a polythene bag and having it tagged with a blue ribbon that indicated its date of bagging and harvesting. All blue-tagged apple bananas began to be harvested at the correct maturity period (90–95 days). Their weight (yield) increased and the desired yellow colour of the fingers became more consistent. They were cleaner, more attractive and less bruised. Bunch sleeved banana fetched 500 shillings (roughly US Dollars 0.3–0.4) more in the local market (relative to an equivalent unit of measure for the un-sleeved banana). It fetched much more in overseas export markets.

But while this premium encouraged other apple banana farmers to adopt and make use of the sleeving technology, potential adopters could not access the required planting material, training, support and advisory services. In the absence of functional collaborative arrangements with local private actors to multiply material on a commercial basis, Kabanyolo research facility could only supply limited quantities of planting material (Hall and Dijkman, 2006). Similarly, no actors were engaged to effectively scale out knowledge and services to new farming households. Adoption remained low and the initial hope of multiplying the quantity produced of high-quality apple banana was difficult to realise.

This initiative also attempted to facilitate at least one Ugandan exporter to make a trial shipment of samples (apple bananas handled under improved methods) to the UK. But because production-related constraints were not dealt with effectively, the attempt to export Uganda's bunch sleeved banana failed because there was simply not enough apple banana to bunch sleeve and export.

In sum, local research institutes worked mostly alone through the apple banana intervention to introduce and test a potentially farmer friendly post-harvest technology. Later, attempts were made to link smallholder farmers to export buyers. The technology showed some promising results by way of increased quality and yield of the apple banana. However, progress was constrained by the inability to engage relevant partners; for example those

that could have continued to avail planting material, those that could have worked to strengthen smallholder organisation and collective capability and those that could have more effectively addressed market related aspects.

CASE STUDY 5:

BUILDING INNOVATION CAPABILITY ON A COLLECTIVE BASIS – THE CASE OF THE ORANGE FLESH POTATO IN UGANDA

The widespread deficiency of Vitamin A in adults and children is a problem that continues to be reported by public health officials not only in Uganda but also across many other developing countries. A project funded by the UK DFID and implemented between 2003 and 2005 through a so-called sweet potato coalition⁵ was implemented in central Uganda to promote the rapid multiplication and dissemination of high yielding sweet potato (SP) varieties and in particular, the Vitamin A-rich orange-fleshed sweet potato types containing *Beta carotene*. The coalition was hosted and managed by PRAPACE.⁶

We are not the first to report this case study. The Orange Flesh Potato initiative was documented and reported before in various forms by the sweet potato project (PRAPACE 2005a, 2005b, 2005c). Nonetheless, in this paper, the case study will be retold as an interesting and positive example of the kind of system building process that pays attention to the interdependence of technical, organisational and 'institutional' change and, to the factors that affect the demand for and use of new knowledge.

The coalition or partnership approach adopted by this initiative was certainly not easy to implement given the many challenges and failures reported. For example, farmers gained entry into new domestic markets but because they lacked knowledge on contracting, they were not always paid for their produce. Training in group dynamics created cohesive groups but a gradual preference for individual benefit weakened collective effort. Despite the many difficulties faced, the available information indicates that the initiative achieved most of its objectives.

To start with, the project had to reverse consumption practices and behaviour that do not traditionally attach value to the nutritional content of food. It also had to overcome the many negative perceptions regarding traits of the new potato. It was new to the local diet and generally perceived as less palatable. Its flesh had an unfamiliar orange colour compared with the usual white. It lacked the usual solidity and firmness and 'did not look natural'. In response, the project designed a targeted awareness campaign that encouraged households whose adults did not want the new potato to at least feed it to infants and children. Results were not satisfactory.

Then, a new public relations and sales campaign involving the ‘promotion’ of the potato by the ‘Nabagereka’ (queen of Buganda’s Kingdom) was developed. Central Uganda is home to the Baganda, an ethnic grouping that is not only the largest in Uganda but also one of the more sophisticated in terms of its clanship system, political history, traditional rituals and beliefs. Be it through the rules and regulations governing the ‘mailo land system’ in Buganda or through the customs and norms jealously guarded through the clanship system, Buganda’s Kingdom and royal family continue to exert a significant amount of influence over the ways of life of the Baganda; the majority of whom trust and honour their King and Queen. Hence, when the Nabagereka was approached and she eventually declared at a publicised event that the orange fleshed potato is a healthier and edible solution ‘needed to improve our nutrition’, its acceptability was dramatic.

Several innovations (technical, marketing, organisational) happened through this project. For example, the use of on-farm storage technologies by some farmers enabled them to store fresh roots for up to three months. “Savings from one hectare using this technology are sufficient to take a family of eight through a dry season of 30–45 days. Diversification of household diets through value addition was introduced to 100 farmer groups of about 20 members each” (DFID R4D).⁷ Of the 14 sites established to demonstrate post-harvest technologies, five became commercially operated and four of these were run by women. Through the coalition, 37 farmer groups of about 20 members each were linked to over 20 locally identified markets including schools, universities, hospitals, traders in vines and, food processing enterprises. Links to export markets were not successful but these segments of the domestic market were new to the farmer and the link seems to have continued beyond the life of the initiative. The coalition evolved into an association (PRAPACE, 2005a, 2005c).

COMPARATIVE OVERVIEW, CONCLUDING OBSERVATIONS AND POLICY INFERENCES

We present a comparative overview of the case studies to highlight emerging insights and use the comparative analysis to draw some inferences for policy.

NATURE OF SYSTEM BUILDING INITIATIVES

In Section 2, we outlined three broad categories or types of system building. They include: (a) System building organised to introduce technology or applications in a new context which we referred to as Type I system

building; (b) System building based on a shift in thinking for instance new or stronger attention to the integration of economic and technological capability development (Type II system building); and (c) System building organised to tackle or respond to changing dynamics in value chains and markets (Type III system building). The categorisation is only meant to highlight the main entry point or motivation for organising a system building process or initiative. Hence, the lines of distinction are loosely drawn and do not in any way imply mutual exclusivity.

At least in the agricultural and agro-industry sectors of countries such as Uganda, one will often find many examples of system building of the kind we have referred to as Type 1. Type II and Type III system building initiatives are not as common and tend to have far less resources in the national system to draw upon; by way of technical expertise, policy competences, cumulative learning, physical infrastructure, positive institutions (habits, attitudes) as well as political and social infrastructures. Design and execution capability for Type II and Type III system building is also often more limited relative to that available for Type I. For example, to respond to changing market dynamics and demands placed upon Uganda's fish processing sector (case study 3), the required guidance and expertise was largely sourced from agencies, buyers and consulting firms based abroad. Type I system building is necessary but clearly inadequate for dealing with the ever changing development challenges and market dynamics developing countries are facing today.

Increasingly, we see more attempts to embrace elements of an innovation systems view in Type I system building. However, there is still a long way to go before several actors acquire a full understanding of what it would take to promote or build systems of innovation. For example, the apple banana bunch sleeving initiative attempted to take on a more innovation systems view but quickly slipped back into old ways of promoting innovation. The Potato coalition initiative was anchored by an innovation systems view but its inability to adequately engage policy actors denied these national level actors a chance to learn and promote similar competence building in other locations and sectors. Theoretical training and guided practice will indeed continue to be important in any competence building processes introduced.

KEY ACTORS AND LEADERSHIP OF THE SYSTEM BUILDING PROCESS

In all five case studies, the public sector played an important role and it worked in collaboration with the private sector to build systems. Private sector research was almost absent and as we saw in the 'push-pull' initiative, in the LSRP intervention and in the apple banana and sweet potato case

studies, public-funded research generated almost all the vital knowledge required. Although the role of research in the fisheries and F&V case studies was limited, its important role is apparent with respect to the search for more commercially competitive varieties in the F&V sector or in the search for commercially exportable fish species that could be locally farmed. The case studies reaffirm that although research has an important role to play, innovation cannot be promoted by research institutes alone. The range of actors involved has to be 'broadly' conceived and both the apple banana and potato coalition initiatives tell us that early involvement of partners and collaborators is essential. In all system building examples provided, we find that there was an 'entrepreneurial' individual, organisation or set of players that served as champions and/or brokers of the learning and competence building process. Collaborative activity, partnerships and coordination were organised, led and brokered by a leading agency and within it, by one or a few individuals. Effective leadership and oversight was a critical component of system building. Champions and brokers seem to have a particularly important role in this process.

LEARNING OF LESSONS AND KNOWLEDGE MOBILITY

One of the conclusions from our case study analysis is that within a national system, there are important sectoral and spatial specificities. These also imply that the same measures, dynamics and policy pack that produce good results in one sector or location do not necessarily produce similar results in another. Actors do not always pay sufficient attention to the variable manner in which lessons and experiences need to be applied. We find that the learning of lessons is much more difficult than previously assumed. Principles underlying small pockets of success often fail to be reproduced and adapted. And, linkages and other mechanisms that allow for mobility of tacit and non-tacit knowledge are often weak. Indeed, if promoters of learning and innovation still expect lessons and positive experiences to flow on their own and be learned and used from one part of the national system to another, the examples discussed in this paper reaffirm that such free flow either happens only very slowly or simply does not happen. The suggestion then is that especially in developing countries, to develop context specific strategies that make it possible to have knowledge mobility, spillovers and intra-system learning is an important issue when building national systems of innovation.

The work reported here only relates to experiences and observations in one developing country context. A key task for further research is to develop and test, preferably through cross-country studies, a set of innovation competence building hypotheses and associated typologies that could

allow for more diverse and broad-based learning to take back into some of the innovation and development theories.

NOTES

- 1 These draw from and build on an earlier classification by Hall, Mytelka and Oyeyinka (2006).
- 2 For an in-depth discussion of data and research findings on learning and innovation in Uganda's fisheries, see Kiggundu, 2006a, 2006b, 2007). The comparative analysis in this section only provides an overview and our interest is to highlight the importance of sectoral specificities in explaining the variable success of learning and innovation initiatives implemented in the same national system.
- 3 European Retail Produce Good Agricultural Practices (EurepGAP). EurepGAP started as an initiative of European supermarket retailers and their suppliers in 1996. The aim was to agree on the development of harmonised Good Agricultural Practices (GAP) and their verification for all sources of supply. In September 2007, EurepGAP changed its name to GLOBALGAP.
- 4 This institute (i.e. KARI) is part of the broader family of institutes under the National Agricultural Research Organisation –NARO.
- 5 The purpose of the coalition was to enable national and international crop-post-harvest innovation systems to respond more effectively to the needs of the poor. The coalition project was implemented for 2 years from 8 February 2003 till 24 February 2005 at a total cost of UK Pound Sterling 95,034. Coalition partners included: (a) Local research institutes (KARI; NAARI; Food Science and Technology Research Institute-FOSRI; Makerere University (Department of Food Science and Technology); (b) International agricultural research institutes (International Potato Centre-CIP); (c) Local training institutes (The Buganda Royal Institute of Business and Technology-BRIBTE; Enterprise Development Limited-EDL); (d) Regional agricultural research network focusing on market-oriented research and information dissemination-FOODNET; (e) Regional Network for the Improvement of Potato and Sweet potato in Eastern and Central Africa-PRAPACE; (f) NGOs (Buganda Cultural and Development Foundation-BUCADEF); and (g) Private sector associations (Horticultural Exporters' Association of Uganda – HORTEXA).
- 6 Regional Potato and Sweet Potato Improvement Network in Eastern and Central Africa.
- 7 DFID R4D, R. Number: R8273: Available at: <http://www.research4development.info/SearchResearchDatabase.asp?ProjectID=3634>

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ABBREVIATIONS

AMA	Agribusiness Management Associates
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ASPS	Agricultural Sector Programme Support
DFID	The UK Department for International Development
EU	European Union
F&V	Fruit and Vegetable
FIFOLA	Fight For Life Association
ICIPE	Centre of Insect Physiology and Ecology
KARI	Kawanda Agricultural Research Institute
LSRP	Livestock Systems Research Programme
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries

NAARI	Namulonge Agricultural and Animal Production Institute
NARO	National Agricultural Research Organisation
NGOs	Non-Governmental Organisations
UNBS	Uganda National Bureau of Standards

Innovation Financing, Industrial production and the Growth of Nigeria's Non-oil Exports

Emmanuel Sebastian Akpan, Hodo Bassey Riman, and Helen Walter Mboto

INTRODUCTION

For those who have been following the economic trend in Nigeria, the country's quest to become one of the twenty most industrialised nations in the world has been a front burner issue of policy discourse. In the year 2007, the International Monetary Fund (IMF), Central Intelligence Agency (CIA) and World Fact Book listed Nigeria as the 41st country on the list of developed economies based on GDP comparison. The World Bank had also listed Nigeria as the 40th industrialised country in its own analysis. The three sources had listed USA, Japan, Germany, China and United Kingdom as the first five industrialised nations of the world. These rankings had assiduously prompted Nigeria government to pursue developmental policies that will not only transform Nigeria's economy, but also project the country as one of the 20th industrialised nations in the world by the year 2020. In order to achieve this vision (Vision 20: 2020) Adewoye (2010) had opined that the nation's economy needs to develop at a rate fast enough to overtake more than 20 countries like Indonesia, Argentina, Saudi Arabia, South Africa and Hong Kong amongst others within the next ten years to come.

Though this desire can be viewed as a "tall" dream, most policy makers opine that this dream is somewhat achievable. The beginning point of realising this quest is by evaluating the past and present innovation, technological and industrial development strategies and policies, particularly, the Structural Adjustment Programme introduced in 1986. The SAP programme was adjudged by many economic critics to have been unsuccessful. As noted by Okoh (2004: 2):

SAP was introduced to revitalise the manufacturing sub-sector through removal of over valuation of exchange rate and subsequent determination by the market forces, tariff reforms, removal of price control to enable producers

operate competitively... Despite the progress made in institutional and structural reforms, increased re-engineering of the financial sector and accelerated growth in crude oil export, it would appear that manufacturing and agro-based industries in Nigeria have not risen to the challenges of meeting up with global competition.

Many researchers have blamed the failure of SAP to achieve the desired goal on (a) Ethno-centric location of industries, particularly, in non-productive areas (Adejugbe, 1980); (b) Lop-sided relationship in the world trade order, the forces of globalisation, extent of competition in the domestic economy, and the extent and order of economic liberalisation (Afangideh and Obiora, 2004); (c) Weak and decaying infrastructures, high cost of importation of machineries for production, poor technical knowledge of the use and operations of these machineries and high and rigid import tariffs (Riman and Akpan, 2010); and (d) Poor utilisation of industrial technology, particularly, the use of obsolete technology, low skill in the usage of these machineries, and mal-application of imported technology (Essia, 2004).

What stands out clearly in the discourse above is the fact that the industrialisation process in Nigeria has been built on faulty foundation. Gwynne (1990) demonstrated that industrialisation growth should be rooted in the constant adaptation and improvement of imported technologies. This opinion could be regarded as the strong pointer as to why the Asian 'miracle' economies are described as fastest growing economies in the world. For instance, the Indonesian economy (which is also one of the fastest growing economies among the HPAEs) had also suffered periods of slump and recovery like most developing nations in SSA including Nigeria. During the 32 years of "New Order" rule (1966–1998) the Indonesian economy experienced rapid and sustained growth, which enabled Indonesia to graduate from the ranks of one of the poorest countries in the mid-1960s to one of the eight "high-performing Asian economies" (HPAEs) in the early 1990s, along with Japan, the four "Asian tigers", and Indonesia's two Southeast Asian neighbors, Malaysia and Thailand (World Bank, 1996).

It is observable that all the policies and programmes that Indonesia government had instituted to revamp their economy were the same policies and programmes that the Nigeria government had likewise instituted in collaboration with the World Bank and IMF to revamp Nigeria's ailing industrial economy. Over the years, the SAP programme recommended by IMF and the World Bank as the panacea to her economic downturn has been described as achieving very little success. The probing questions in the minds of economic watchers and industrialists are, if these structural programmes policies (which were also recommended by IMF and the World Bank to the Asian Tigers) were effective in transforming the agro-based

economy of HPAs why has the same policies failed to yield similar result in Nigeria? Furthermore, what should Nigeria policy makers do to strengthen industrial development programmes in Nigeria?

The objective of this research to examine industrial innovation strategies of selected countries, with a view to emulating their innovation strategies, develop a stronger innovative and technology capability that will be capable of creating a more skillful and technology intensive economy that will promote manufacturing export as well as encourage competitiveness of Nigeria's non-oil exports internationally. It is expected that this research will guide policy formulation not just for Nigeria, but also for other developing countries in Africa.

The research paper shall utilise the lessons from other technologically developed countries to answer the following research questions.

1. Why has the industrial sector in Nigeria not responded correspondingly to the numerous economic and industrial policies and funding so far expended on the sector?
2. Given the current state of industrial development in Nigeria, can the industrial sector be said to be the driver of the country's domestic economy?
3. What future does it hold for the country if the trend in dismal performance of manufacturing production continues unabated?
4. What innovations strategies should be introduced to enhance an efficient and effective industrialisation process in Nigeria?

In attempting to answer the research questions enunciated above the paper shall employ the Ordinary Least Square (OLS) technique and Descriptive methodology to establish the relationship between the variables. The study period of this paper shall begin from 1980 to 2008. The study shall utilise data produced by Federal Office of Statistics (FOS), Financial and Statistical Bulletin from the Central Bank of Nigeria and relevant journal publications.

THEORETICAL BACKGROUND AND REVIEW OF LITERATURE

A country's innovation system is a set of institutions, procedures and processes that determine how it can create, acquire, disseminate, and use knowledge and information. Innovation is considered as the application of knowledge in the various stages of production processes. This knowledge might be acquired through learning, research or experience, but until it is applied in the production of goods or services it cannot be considered innovation (Adewoye, 2010). Innovation programmes are often acquired

and transferred through institutional network of coordination between universities, research centers, think tanks, firms, business associations, and, more generally, producers and users of knowledge in the country. To emphasise the importance of knowledge-driven economy in enhancing industrial production and market competitiveness, Salmi (2009) acknowledges that a successful knowledge economy is such that collaborates and forms a close linkage between academia, science research institutes and industrial technology centres. Furthermore, innovation fosters economic growth and competitiveness, increased significance of education and life long learning, and greater investment in intangibles, such as R&D, software, and education (World Bank, 2005). The current thinking in economics today is focused on how to improve industrial innovation to enhance competitiveness in world market.

Haberleger (1988) observed that trade is a means and vehicle for disseminating technological knowledge, the transmission of ideas, the importation of know-how, skills, managerial talents and entrepreneurship. This therefore means that for trade to benefit participating countries, the developed countries must allow the transmission of technological innovations, ideas and managerial talents across borders to the LDCs. Likewise, the LDCs must also demonstrate willingness to imitate the technological ideas of the developed countries. This opinion was resounded by Essia (2004: 67) that:

In the technological-gap models, it is supposed that additions to the stock of knowledge generated in one country would have positive externalities for firms located in that country first. But international spillover to and imitation by firms in other countries would occur over time. Hence it is argued that countries with relatively high technological advantage should “innovate” while technologically weak countries should “imitate”.

In other to encourage “imitation” and “innovation” between developed and developing countries, the barriers of trade were dismantled in the 1950s and 1960s. This condition gave birth to tremendous growth initiatives and innovations among countries in the world. These initiatives promoted growth amongst developing countries that adopted outward and inward looking trade policy as a strategy for structural economic reform in the 1970s and 1980s. Thus, countries that were to benefit from the new World Trade Order had to produce goods and services that were competitive and export oriented. Industrial production suddenly became the engine that was perceived to drive the growth of domestic economies. Consequently, countries began adopting and implementation industrial development policies that were geared towards promoting qualitative changes in the structure of domestic economy with the ultimate resultant effect of

promoting sustainable growth, based on efficient utilisation of both human and material resources.

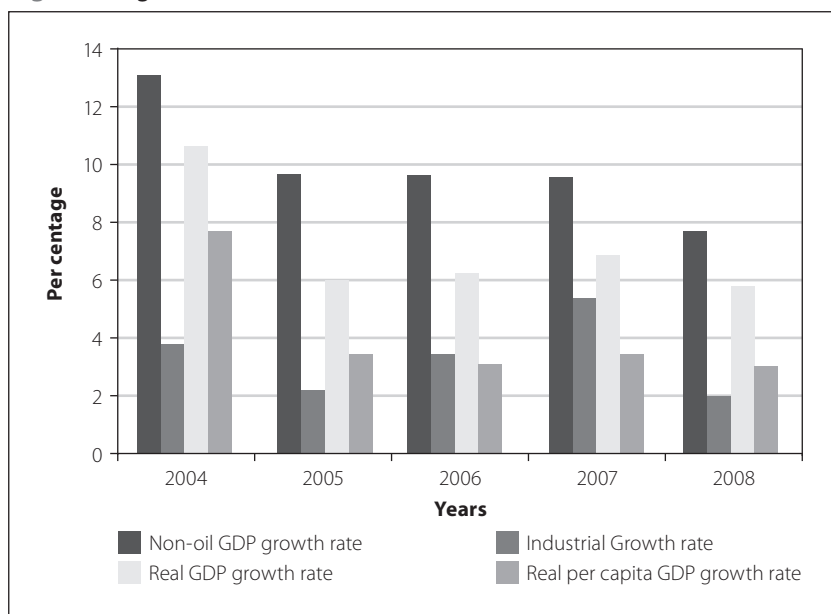
The burden of adopting new technology to improve industrial development has grown over time as the initial costs of technology and plants have increased due to rising capital intensity and the scale of modern production. The problems of inadequate skilled labour and insufficient technical and managerial talent has made it even much more difficult for newcomers like the LDCs to choose the latest and best equipment for industrialisation (Alokan, 2005, Abu and Ogenekohwo, 2010). Furthermore, the smaller countries of the Third World have markets that are insufficient for the supply of goods that would emanate from imported plants essentially geared to large economies of scale and production runs (Gwynne, 1990).

The major distinguishing element between the industrialised and industrialising nations as noted by Essia (2004) is not the encumbrances associated with poor market access and demand for local goods and services emanating from the industrialised nations at the international market, the level of sophistication in R&D activities, access to underlying disembodied technology, widening gap between technology using and technology-changing skills, and knowledge integration and transfer. Iyoha (1995) also opined that the state of a country's technical knowledge and progress can determine the economic growth and development of developing nation. This is probably why neo-technological experts broadly agree that for LDCs to benefit from import/export trade, technology should have the ability to leak in much the same way to developing countries as it did among firms in today's industrialised countries during the early stages of their technological transformation.

The force of innovation is amplified in the sudden emergence of the East Asian countries from a traditional economy to neo-technology economy. The rapid growth of the East Asian region as technologically developed countries has indeed been unparalleled. The eight High Performing Asian Economies (HPAES) Hong Kong, Indonesia, Japan, Malaysia, Singapore, Taiwan and Thailand have not just out-performed other industrial economies since 1960, but they have also grown at rates faster than other developing economies of the world. One remarkable feature of the East Asian "miracle" is that growth has been achieved alongside reduction in income inequality. The emergence of East Asian economies was only possible because technological capabilities were employed to produce goods and services to meet human needs beyond the basic necessities of subsistence (Bell and Pavitt, 1993).

ASSESSING THE PROBLEMS OF INDUSTRIALISATION IN NIGERIA

The importance of industrialisation as an engine of economic growth and development cannot be overstated. Industrial production creates job

Figure 1 Nigeria Economic Indicators

Source Computed from CBN (2008), Statistical Bulletin

opportunities at higher skill levels, facilitates denser links across the service and agricultural sectors, narrow the gap between rural and urban economies (Opara, 2010). In addition, industrialisation is a critical tool in poverty eradication, employment generation, and regional development policies. It can spur technological advancement and innovation as well as productivity gain and is hence able to play the development role more suitably than the agricultural sector (Marti and Ssenkubuge, 2009).

However, the industrial sector in Nigeria has continued to witness unsteady growth since after the introduction of the Structural Adjustment Programme (SAP) in 1986. Prior to the introduction of SAP Industrial sector contribution to GDP was observed at 11 per cent between the period of 1973-1981. The highest performance of 45.85 per cent noticeable in Nigeria's industrial sector was achieved in 1995, while manufacturing sub-sector and non-oil export contributions to GDP was 7.44 and 1.14 per cent respectively (Ikpeze, Soludo and Elekwa, 2001). Thereafter, the performance of the sector had taken a continued down ward trend.

Evidence in Figure 1 suggests that Non-oil GDP growth rate at 2004 was 13.30 per cent. This figure took a gradual summersault to 7.6 per cent in 2008. Industrial Production growth rate which stood at 3.7 per cent in 2004 rose to 5.3 per cent in 2007 and thereafter slumped again to 2 per cent in 2008. The nations real per capita GDP rose to 7.6 per cent in 2004 and thereafter declined to 3 per cent as observed in 2008. What could have been responsible for this dismal performance noticed in the industrial sector in

Nigeria? A research carried out by Adejugbe (1980) subtly attributed the Nigeria's poor industrial performance to frequent muddling of policies by incumbent government and abrupt modifications and interruptions of existing and ongoing industrial programmes and strategies established by previous government. Each government that comes into office will recklessly abandoned existing programmes to begin a new programme, thus truncating the growth process. Adeniran (2005), Enang (2010) and Onyeonoru (2003) associated the poor performance to Nigeria's poor and sub-optimal electricity supply which is often below the installed capacity utilisation. Ajayi (2007) associated the industrial problem with industrial sub-contracting, limited size, polarised structural characteristics of contracting firms and concentration of firms in some geo-political zone, particularly, the Western and Northern region of the country.

Ogunlade *et al.* (2008) furthermore observed that the problem that greatly limits the production of agricultural produce in Nigeria is the inability of large farmers to access funds to improve their innovation. They further decried the situation where farmers still rely on old implement of agriculture to cultivate large hectare of land. So, if agricultural extension farmers must improve production attention must be given to innovation financing.

Isern *et al.* (2009) argued that the major problem confronting industrialisation in Nigeria is the inability of firms to access investible funds. They noted that while access to finance is low, basic knowledge of financial services is even lower. While the level of financial literacy among Nigerian adults is extremely low for several types of services, knowledge about financial opportunities for investment development is even lower. Their research noted that at least 46 million Nigerian adults are currently excluded from the banking system, and a majority of those financially excluded dwell in rural areas.

This axiom appears to hold, particularly if we consider the ratio of loans granted to SMEs by Commercial Banks in Nigeria. Evidence suggests that in 2000 commercial banks loans to SMEs as a per centage of total credit stood at 8.7 per cent. This figure dropped down to 2.7 per cent in 2005 and a further drift to 0.9 per cent in 2007. This raises the concern that the level of credit granted to SMEs which is suppose to enable them pursue innovations in agriculture and manufacturing is inadequate. This continuous drift in SMEs funding put a question mark on the willingness of the banks to finance innovations by industrialists in Nigeria.

PROBLEMS OF INNOVATION FINANCING, BUSINESS DEVELOPMENT AND TECHNOLOGY ACQUISITION

The main channel of innovation and technology transfer in Nigeria has been traditionally through FDI. However, FDI involvement has only been limited

to oil sector. But quite recently, FDI involvement has spread to the non-oil sector through the ongoing privatisation process with limitations to only some productive sectors. FDI involvement in industrial development and industrial project financing had been limited to only large multinational organisations. The smaller firms leverage for their investment funding from private savings, consumer borrowing and plug-back profits.

Innovation financing of small business strategy as an option of industrial development is gradually gaining importance as a theme of discourse in public policy with much concentration in business strategy development. This body of interest arises from the realisation that smaller firms have some initiatives which if properly harnessed can dramatically change national output. The strategy that strongly enhanced the East Asian industrial development has been their ability not only to developed R&D, but also juxtaposing their educational institutions to manufacturing industries. Aloa and Adelabu (2006) noted that the problem with Nigeria's innovation began with the system of education inherited from the British colonial powers which was specifically designed to serve the service and manpower needs of the colonial political and economic structures. Since after independence the status quo had not changed from what was left behind by the British. Ever since then, the country has proposed and pursued disjointed and unarticulated educational systems.

To enhance innovation, developing countries have embraced educational system that interlocks with the manufacturing industries. University-industry collaboration could stimulate the integration of financing mechanisms for research and development within the education and industrial system. Further dimensions of the collaboration between University-Industry can be strengthened through mutual identification of research themes or project, active participation of government as major financier of committed R&D project, location of specialised universities in an industrial park or near an industrial cluster where businesses related to the specialization are thriving, linking Nigerians in the diasporas through university industry network (Adeoti, 2002).

Agwu *et al.* (2008) while investigating the reason for the poor agricultural output in Nigeria did not find clear evidence of inter industry-linkage between actors in agricultural research institutions and agro-based industrialist. Research Institutes were observed to operate in isolation of the universities. Although researches were taking place at various national and international research units within the country, coordination with research units was dysfunctional, and poorly linked to the productive sectors. Farmer innovations were not being included in the knowledge system, while private sectors involvements are discouragingly weak. According to Agwu *et al.* (2008) agricultural innovation system

in Nigeria will remain dysfunctional unless the government encourages and promotes farmers' and private sector innovation by enacting favorable policies (patenting, reward system), while extension administrators should by training build capabilities to facilitate, analyse and promote farmer innovations.

Adeoti and Adeoti (2008) who investigated the innovation capacity of agro-industries in Nigeria demonstrated that the technological trajectory in industrial innovation in Nigeria is still at the initial conditions of articulating the frameworks for technological learning, building infrastructure for R&D, and providing adequate and appropriate incentives for industrial innovation. The existence of technological innovation in the Nigerian agro-industry has been limited to anecdotal incidence of industrial innovation. The current situation therefore points to the necessity of integrating industrial and technological policies in an innovation policy that detail specific sectoral strategies for stimulating a dynamic industrial innovation system with a focus on agro-industry.

Pockets of research institutes established by the Federal Government of Nigeria exist at various geopolitical zones within the country. Most of these established institutes have fundamentally remained unfunded, particularly, as it relates to motivating research students to carry out research practices. There has also been huge exodus of Nigerians to developed countries with particular intention of undertaking research on how to improve technological development in Nigeria. The appalling issue is that most of those who leave the country on such purposes do not find their way back to the country. This situation had prompted the government in 2006 to initiate and establish a forum of all Nigerians in Diaspora. This forum is to provide source of new ideas and financing for targeted investments and points of entry for developing new markets. Despite these initiatives the level of innovation financing is still uncultivated.

Adewoye (2010: 6) attributes Brain Drain as a major cause of the inability of the Nigerian Science and Engineering capabilities to transform into sustainable national development. He states:

The Nigerians in Diaspora are estimated at between 17–20 million, a significant fraction of these are professionals. There are about 5,000 Nigeria medical doctors practicing in North America. This continuous outflow of skilled labour has contributed to widening the gap in S&T between Africa and other continents. Even the United Nations once stated that the emigration of African professionals to the West is one of the greatest obstacles to Africa's development.

Adewoye (2010) further expresses that other challenges to harnessing Nigerian Science and Engineering innovation capabilities for sustainable

national development include: Lack of conducive integrated policy and institutional framework; under-developed technology and innovation promotion capabilities; system linkage failures and poor coordination; disconnection of application of new technologies from socioeconomic problems; scientific institutions with strong and inflexible disciplinary focus; low technology and innovation diffusion between and within industries; and lack of funding for technology acquisition and diffusion. Adewoye (2010) therefore advises that for Nigeria to tap from the abundant available investment opportunities, the nation manufacturing processes must be reoriented to adopt STI and apply the best practices in production and processing technology in their operations, for products of high standard and quality that will meet international demand.

CROSS-COUNTRY INNOVATION STRATEGY AND TECHNOLOGY ACQUISITION

Traditionally, innovation is seen as the process of combining resources in new or unusual ways to generate new or improved products (goods and services) and processes. These improvements or advances may range from slight improvements on existing ones to major leaps in performance and changes in technology systems and economic paradigms. These technological innovations will not be possible without significant investment in research and development (R&D) and education, which generate basic scientific and technological knowledge upon which innovations are based (UNECA, 2010). On the whole, the production of competitive and export oriented goods and services is the major focus of state innovation, industrial innovation and development policies. Below are the extracts of innovation strategies of selected countries.

MAURITIUS

Mauritius is probably the most impressive newly industrialised country in Africa with a clear example of innovation financing. It has grown rapidly in the past 20 years, with manufactured exports rising from 27 per cent of total exports in 1980, to 68 per cent by 1996. Technology support in Mauritius has grown with manufactured exports, supported by external projects.

Several institutions are involved in ensuring, standard, testing and quality assurance, productivity improvement, training and support for small- and medium-sized enterprises. The official body in charge of these services is the Mauritius Standards Bureau (MSB), which, according to field surveys of local enterprises, provides high quality services.

In the mid-1990s, the World Bank gave Mauritius US\$3.5 million loan as part of a technical assistance to enhance competitiveness among project. The local government gave the MSB US\$1.5 million at the same time. The bureau was also 'twinning' with the Singapore Institute of Standards and Industrial Research to upgrade its expertise. Both the World Bank project and the twinning arrangement have greatly enhanced MSB capabilities.

The Technology Diffusion Scheme (TDS) was a World Bank project, set up in 1994, to create a market for technology services by lowering their cost for a limited time. It was hoped that subsidising costs would support private firms' demand for consulting services, increase the use of these services and make them more accepted by industry. This was expected to generate spillover effects for other firms. The project started with US\$2.7 million to be disbursed over four years. It was set up under the Ministry of Industry and Industrial Technology, and managed by a private sector contractor. Preliminary indications show that the project has been successful (Pietrobelli, 2006: 6). Mauritius has since the years pursued the objective of financing various innovation initiatives of small and medium industries. These initiatives culminated in the expansion of export base of the manufacturing sector and foreign exchange earning of the country.

BRAZIL

Sennes (2009) while studying the Brazilian innovative system recommended the creation of environments that are favourable for interaction between players, with a vision for long-term investments that manage both the high costs and risks involved in the innovation process. Sennes (2009) listed policies that enhances Brazil's industrial innovation such as: (a) Policies that aim at promoting productive activity, directed at development stages that are longer than pre-existing ones; (b) Foreign trade policies, with import policies used to protect nascent industries, and export policies that help increase the competitiveness of national industry against international competitors; (c) Promotional and financing policies that enable long-term investments and the development of new technologies with research and development (R&D) expenses; (d) Policies for competition and regulation that aim at creating and maintaining a competitive economic environment in critical areas for innovation, including intellectual property policies; (e) Policies to support micro-, small- and mid-sized enterprises (SMEs) that have been able to play a significant role in innovative economies; and (f) Education policies to train skilled labour and in the fields of science, technology and innovation that promote and stimulate the generation of

knowledge in society by supporting academic and scientific research. These public policies that led to the stimulation of innovation in Brazil are increasingly being adopted by developing countries to create a favourable environment for long-term investment, R&D, and the development of new products (Lundvall and Borrás, 2005).

IRAN

Iran has pursued a development strategy of self-reliance with some measure of success. Endowed with abundant oil and natural gas resources, Iran did not face an import constraint. Yet, Iran adopted an import substitution policy and used its oil revenues to acquire foreign technologies to industrialise. Iran is today a middle-income developing country, with a significant industrial base, a relatively well-developed science and technology infrastructure and good human development. To boost the industrial base of the economy the government proposed policies that enabled a shift to a more knowledge-based economy, requiring creating a national innovation system that can not only import and adapt technologies, but also improve upon them, innovate new technologies and diffuse them economy wide (UNIDO, 1999).

UNCTAD (2005) report indicated that a number of innovation strategies were designed by the Iranian government to encourage firm-based competition among industries and further promote the country's product at the international markets. These included: (a) Establishment of a measurable short-term, medium-term and long-term objectives and programs focused on fostering learning and linkages; (b) Strengthening measures to support transparency and accountability through setting up a system for monitoring and evaluating policies and programmes (strengthen the collection of economic data and information on science and technology inputs and outputs and initiate periodic firm-level innovation system surveys); (c) Fostering research and technological capacity through joint ventures and licensing agreements; (d) Implementing sectoral innovation strategies through applying the concept of "technology-missions" successfully adopted by several countries, including Japan, the Republic of Korea and India in formulating such a strategy (this concept involves formulating specific measurable objectives to be achieved in a selected sector within a specified time and detailed plans to achieve these objectives); and (e) Strengthening user-producer links, prioritising SMEs through entrepreneurship training, advisory and facilitation services, human resource development, business management, marketing, mentoring, counseling, networking, financial and personnel management, legal assistance, and export assistance.

KOREA

Korea built up a deep and diverse industrial structure by virtue of deliberate interventions in the trade and industrial regime, guiding the allocation of industrial investments in particular directions largely under the control of national private firms. Private firms import technology mainly in the form of equipment and licenses, thereby relying relatively little on direct foreign investments (FDI). As industries enter more complex activities and approach the frontiers of their technologies, local R&D became imperative to keep abreast of world levels of competitiveness. To enhance inter-industry linkage, Korea established research linkage with research institutes and universities where enormous studies were undertaken on industrial development.

Human development efforts in Korea were met by massive investments in higher level technical education and induced firm-level training. Financing requirements were initially left to the existing financial intermediaries, supplemented by a number of instruments to support R&D in approved projects by the *chaebol*. The S&T infrastructure received a lot of financial and human resources assistance, and Korea seemed to succeed in establishing good linkages with industry. These measures led to spectacular increase in private R&D and an attitude to undertake technological activities that enabled Korea to achieve its main industrial ambitions. Korea however faced some challenges particularly on how smaller firms innovators from the crisis of financial market failures, and how to help the research infrastructures to enter more areas of activity to promote the government's industrial strategy (Balino and Ubide, 1999).

INDONESIA

Indonesia's economy experienced rapid and sustained economic growth soon after the "New Order" rule (1966–1998). Indonesia's economic growth was driven by the expansion of the three main sectors of the economy, namely, agriculture, manufacturing and services. The manufacturing sector throughout this period grew at double digits, much faster than the two other sectors which were growing at single digits. Indonesian economy also underwent a rapid transformation, as reflected by the rapid decline in the relative importance of agriculture in the economy and an equally rapid rise in relative importance of the manufacturing sector (Thee, 2005).

Indonesia's rapid industrial growth was initially fuelled by the liberalisation of economic policies, particularly the liberalisation of the trade and foreign investment regimes. However, following the Asian crisis, Indonesia experienced a sluggish growth in her manufacturing export. This situation

which provoked a slump in Indonesia's domestic economy, subsequently led to upgrading of the country's industrial technological capabilities. The technological capacity of Indonesia is built on: (a) Pursuit of sound macroeconomic and pro-competitive economic policies, which is premised on the assumption that competitive environment is conducive to drive firms to rapidly adopt, diffuse new technologies, and make an effective choice and efficient use of new technologies; (b) Expanding education and upgrading the human technical capacity; (c) Improving the manufacturing firms' access to foreign technology through foreign direct investment (FDI), technical licensing agreements, capital goods imports, and foreign trade; and (d) Improving the availability of adequate finance for technology development (Thee, 2005). The most important of the policies formulated was improving manufacturing access to foreign technologies.

The major channels through which these technologies have been transferred to Indonesia, particularly, to its manufacturing sector are foreign direct investment (FDI), technical licensing agreements, capital goods imports and the related transfer of skills by technical experts of foreign supplier firms, and technical and marketing assistance by foreign buyers of some of Indonesia's manufactured exports. Quite remarkably, before the Asian economic crisis, finance for investments in technology development was scarce. Indonesia never had a financing firm for technology development (World Bank, 1996: 2). However, after the Asian economic crisis, the bulk of the loans from the banks have been provided for private consumption, which indeed has been the main driver of economic growth during the past few years. At present, banks and non-financial institutions have provided large amounts of loans for housing loans and credit card lending and SMEs.

METHODOLOGY

The methodology used for this research is carefully selected to answer the research questions presented previously. Thus, the econometric model will analyse the correlation and inter-relatedness of the variables used for the study.

DATA COLLECTION

The data for this study are secondary data and of the time series type. They were extracted from various statistical bulletins to cover the period 1980 to 2008. Basically, the sources include: Federal Office of Statistics (FOS), 2008 Financial and Statistical Review, Central Bank of Nigeria (CBN)

Annual Report and Statements of Accounts, Nigeria Financial and Economic Reviews, Statistical Bulletin and the CBN Bullion.

The study shall utilise annual time series data from 1980 to 2008. One of the characteristics of the data in less developed countries is the weaknesses in their data base thereby creating doubts on their usefulness for projections or guide to policy formulations. Nigerian data does not escape this shortcoming. However, the data used in this study have been verified and certified by external auditors. Thus, the data utilised are not without perfectionist despairs.

MODEL SPECIFICATION

The research shall utilise the Ordinary Least Square (OLS), and descriptive techniques to analysis the relationship between the variables. The selection of this estimation procedure is considered suitable, because of its advantages over other estimation methods, besides, these techniques of analysis satisfies the Gauss-Markov least squares criterion of providing the best, linear and unbiased estimates (Wannacott and Wannacott, 1970). The study carefully considered variables that are assumed to impinge on industrial development in Nigeria. The variables are defined as shown in Table 1.

Table 1 Definition of Variable

GDP	Total Gross Domestic Product of Nigeria
NONOL	Non-oil Exports (representing the total value of non-oil exports traded). Lall, (1998:138) suggested that this figure can also be used as an index for technological sophistication
DLM	Credit granted by Deposit Money Banks (DBMs) towards industrial development, representing the level of financial innovation of Nigerian industries.
INDP	GDP of Industrial Pr i Industrial Production
DCSMC	Credit granted by Deposit Money Banks credit to Small and Medium Scale Entrepreneurs.

From the discussions on previous sections, some of the factors identified to influence industrial production in Nigeria were, poor accessibility of funds by SMEs from the DMBs, limited financing of industrial development by DBMs, and information asymmetry that exist between industrialist and DBMs. The measure of information asymmetry was excluded from the analysis since it will require primarily questionnaire administration to extract the required data. The definitions of the variables are indicated above.

The functional relationship is of the form:

$$\text{INDP} = f(\text{GDP}, \text{DLM}, \text{DCSMC}, \text{NONOL}) \quad (1)$$

where the signs directly below each variables is the expected effect of the dependent variables depending on the interplay between the dependent and independent variable. Operationally, the estimating equation is of the form

$$\text{INDP} = \alpha_0 + \alpha_1 \text{GDP} + \alpha_2 \text{DLM} + \alpha_3 \text{DCSMC} + \alpha_4 \text{NONOL} + \mu_t \quad (2)$$

$\alpha_1, \alpha_2, \alpha_3, \alpha_4 > 0$, *a priori*, it is expected that all the dependent variables should have value above zero.

The logarithmic form of the equation is presented below,

$$\text{INDP} = \alpha_0 + \alpha_1 \log \text{GDP} + \alpha_2 \text{DLM} + \alpha_3 \text{DCSMC} + \alpha_4 \log \text{NONOL} + \mu_t \quad (3)$$

Where α_0 is the constant term and $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ are the parameter intercept of the variables and μ_t is the error term.

PRESENTATION OF EMPIRICAL RESULT

The results show (see Tables 2 and 3) that the explanatory variables account for 99 per cent of the variation in the Nigerian industrial growth process. Though most of the variables were significant in explaining the growth of industrial process, some of them were not of the expected signs. For example, NONOL came up significantly but without the expected sign, implying that non-oil (manufacturing) export is a significant variable that should accounts for improvement in industrial growth in Nigeria. However, manufacturing non-oil export in Nigeria suffered negative growth over the sampled period. Indeed, the dismal growth performance witnessed in Nigeria could partly find explanation from the poor performance and contribution of in the non-oil export.

The extent to which Small and Medium Scale industries (SMCs) access funds from the financial institutions (DCSMC) is captured by the ratio of credit offered by commercial banks to SMEs as per centage of Total Commercial Bank credit. This variable came up with the expected sign though not significant. The result explains that two per cent growth in industrial development is explained by loans to SMEs. This value explains the insignificant level of loans offered to SMEs by credit institutions for the development of industrial and business strategies in Nigeria. It is worthy to note that SMEs constitute the majority of business environment in Nigeria. Therefore, factors that impinge on SMEs performance will correspondingly affect economic growth in Nigeria. The analysis above implies that the

Table 2 Presentation of Empirical Results

Constant	GDP	DLM	DCSMC	NONOL
-0.547	0.327	0.00336	0.0235	-0.0227
0.357	0.060	0.024	0.022	0.034
P-values	0.000	0.875	0.305	0.052
R ² = 0.995 R ² Adj = 0.993 F-stat = 608.483				
DW = 0.9910 AIC = -2.0874				
SC = -1.842 Prob(F-Statistic) = 0.00000				
Dependent Variable: INDP 1980 – 2008				

Table 3 The Result of the Descriptive Test

	GDP	INDP	NONOL	DLM	DCSMC
Mean	4733037.	3339339.	36460.31	302046.2	45288.67
Median	1419418.	578723.9	12420.80	48740.75	20476.25
Maximum	24235217	60905474	169709.7	1392839.	408443.7
Minimum	50456.10	13596.90	203.2000	2659.200	0.000000
Std. Dev.	7166308.	11406710	49193.59	430068.0	85550.02
Skewness	1.713077	4.835884	1.294985	1.276468	3.235871
Kurtosis	4.681384	24.91933	3.386174	3.385142	13.43519
Jarque-Bera	16.99318	669.6666	7.999919	7.776785	175.9061
Probability	0.000204	0.000000	0.018316	0.020478	0.000000
Sum	1.33 E+08	93501494	1020889.	8457293.	1268083.
Sum Sq. Dev.	1.39 E+15	3.51 E+15	6.53 E+10	4.99 E+12	1.98 E+11
Observations	28	28	28	28	28

SMEs have not been able to access the required amount of funds necessary for industrial development.

RESULT OF DESCRIPTIVE ANALYSIS

The level of innovation financing (DLM) is measured by the amount of credit offered by Deposit Money banks (DMBs) to Nigeria manufacturing industries. The result shows that though the variable (DLM) had the expected sign but was insignificant. The result of the analysis suggests that the manufacturing industries have not properly and adequately been mobilised financially to develop their technological capability. The quantum of financial innovation is explained by the fact that less than three per cent of industrial growth is traceable to credit offered by DMBs to industries. This result amplifies the opinions of Isern *et al.* (2009), Ogunlade, Adekunle and Akangbe (2008) that the major problem confronting industrial growth in Nigeria is accessibility to funding by industries.

Gross domestic product (GDP) had a mean average of N4,733b and varied from N50,456b to N24,235b. Non-oil Export (NONOL) and Credit to Manufacturing Industries (DLM) had mean average of N36m and N302m respectively. Non-oil (manufacturing) export varied from N203m to N169m, while Credit to Manufacturing Industries varied from a minimum value of N2,65m to a maximum value of N1,392b. The variable representing the amount of funds available for financial innovation by SMEs (DCSMC) has a mean of N45m with a minimum value of 0.00 and a maximum value of N408m. It is worthy to note that the measure of skewness indicate not only the amount of skewness but also the direction. A series is said to be skewed positively if it is skewed in the extreme direction. The result indicates that all the variables are positively skewed, that is, the variable is skewed to the right. The Jarque-Bera (JB) test of normality indicated that all the variables are normally distributed. This normal distribution is also confirmed by the p-values which are extremely low. The values of the standard deviation indicate that of all the variables exhibit wild swings and variability.

CONCLUSIONS AND POLICY RECOMMENDATIONS

The research adopted the empirical analysis approach to identify the reasons why the industrial sector in Nigeria has not responded correspondingly to the numerous economic and industrial policies so far expended on the sector.

The research result suggested that lack/poor access to finance by industries and SMEs posed as the major challenge to development of the industrial sector in Nigeria. This was evident by the insignificant and insufficient amount of DMBs loan and advances to Small and Medium Scale Entrepreneurs. These results further suggest that industries in Nigeria suffer paucity of funds required to develop their innovation strategies. The drought in finances to manufacturing industrial could also account for the poor contribution of non-oil exports to economic growth. This result confirms Oyelaran-Oyeyinka (1997) and Radwan and Pellegrini (2010) that only large firms gain access for industrial financing, while smaller firms continue to suffer exclusion.

Most Nigerian industrialists are endowed with a huge potential of creating new innovations and developing new techniques for industrial growth. However, due to their inability to access sufficient funds necessary to transform these innovations to modern technology, most techniques used for industrial processing are still crude, primitive and sub-standard. The study therefore submits that, much as the country is investing on promoting R&D, inter-industry linkage between industries and universities, and improving FDI penetration through providing a conducive friendly business environment, these strategies will not yield the full expected results unless the country strengthens her financial and institutional framework that will: (a) Allow smaller firms to access funds from financial institutions at a lower cost; (b) Permit the deployment of these funds to productive uses which will allow entrepreneurial activities to flourish; and (c) Monitoring the usage of leveraged funds. Innovation financing seems to be the plausible option required to revive and sustain the potentials of Nigerian manufacturing industries.

Drawing inference from Indonesia and Korea technology development, the study therefore proposes that while Nigeria continues to adopt appropriate technology to run the country's manufacturing sector through technology importation, it will also be necessary if policies are formulated and strengthened through enacting legislations that will enhance financing of indigenous innovations, particularly, those that will come from SMEs. The paper therefore proposes innovation financing strategies that will:

1. Sustain financing of R&D activities through public-private partnership in the country should be encouraged by establishing appropriate financing modalities to support the implementation and use of R&D results in the country;
2. Fund and strengthen capacities to build up skills and develop technologies that improve efficiency and productivity along current R&D results based on local demands and needs;

3. Strengthen the capacities of linkages among public-private agencies responsible for R&D, financial sector and entrepreneurs in the manufacturing sectors;
4. Finance entrepreneurs that are involved in R&D activities who are innovative. Typically, innovation results from a conscious purposeful search for opportunities;
5. Encourage banks to periodically organise boot camps for entrepreneurs on entrepreneurial development and skill acquisition. Such boot camps should be anchored in collaboration with the Science Technical Institutions (STIs) and universities;
6. Formulate policy aimed at supporting SMEs to develop and produce the inputs/components needed by the large state-owned enterprise at competitive levels will promote innovation and help in building up the support industries that can compete in the export markets. Lessons can be drawn from the success of automotive component manufacturers in countries such as Thailand and India in becoming global suppliers; and
7. Increase the involvement of FDIs in the activities of Small and Medium Enterprises (SMEs). The SMEs constitutes the bulk of industrial businesses in Nigeria.

Finally, rapid advances in information infrastructure are dramatically affecting the acquisition, creation, dissemination, and use of knowledge, which in turn affects economic and social activities, including how manufacturers perform their functions. To develop a strong information infrastructure, it is necessary to mobilise the many stakeholders involved in its deployment and use. One of the strongest information to be made available to manufacturers is how they can access funds readily and at a cheaper cost, and this is the hallmark of financial engineering.

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ABBREVIATIONS

SAP	Structural Adjustment Programme
HPAEs	High Performing Asian Economies
WTO	World Trade Order
R&D	Research and Development
SMEs	Small and Medium-Scale Enterprises
TDS	Technology Diffusion Scheme
FDI	Foreign Direct Investment
CBN	Central Bank of Nigeria
FOS	Federal Office of Statistics
DMBs	Deposit Money Banks
UNCTAD	United Nations Conference on Trade and Development
IMF	International Monetary Fund
LDCs	Less Developed Countries
STI	Science Technology Institute
MSB	Mauritius Standards Bureau
ITD	Industrial Technology Development
SSA	Sub-Saharan Africa
S&T	Science and Technology

A Firm-Level Analysis of Technological Externality of Foreign Direct Investment in South Africa

Abdelrasaq Al-Suyuti Na-Allah and Mammo Muchie

SUMMARY

This paper examines how Foreign Direct Investment (FDI) impacts on productivity performance in host economy by raising and addressing two key questions: (a) To what extent does technological externality of FDI (FDI Spillover) rely on host economy's skill deficiency characteristic before it can be generated and appropriated? (b) Is there a regional dimension to the level of spillovers from multinationals to domestic firms? Using establishment level data for the South African economy, we estimate regression equations for a representative sample of her manufacturing plants. Our findings reveal that regardless of the environmentally imposed skill deficit factor, foreign firms are able to generate productivity spillovers for their host. Successful diffusion to domestic firms is however mediated and significantly circumscribed by the skill factor. It also appears that some support exists for the claim that level of FDI spillovers to domestic firms relies on regional presence, i.e. closeness to the region in which foreign firms locate.

INTRODUCTION

For much of the developing world, the decade of the 1980s was a turning point in experimental economics as market pessimism gave way to measured optimism in development policy engineering. The abandonment of import substitution strategies that were principally influenced by the dependency and Neo-Marxist theories of earlier decades saw governments across the South adopting many of the neoliberal policies of open and free market orthodoxy. As a major pillar of this new economic model, attracting foreign direct investment (henceforth, FDI) into the local economy became a policy priority for many governments. Consequently, varieties of generous

investment incentive packages were developed by these governments in order to turn their economies into attractive destinations for investors.

For South Africa, this has been especially the case since the dismantling of Apartheid and subsequent formation of the democratic government in 1994. With her new found status as an integrated member of the global economy, the country joined the club of FDI contestants through its pronounced Growth Employment and Redistribution (GEAR) strategy in 1996. Several inducement packages were introduced at both national and provincial levels of governments to foster the growth of national stock of foreign capital. Besides being a signatory to the Trade Related Investment Measures (TRIMS) Agreement as well as over 30 bilateral investment treaties that have, as priorities, increasing the national stock of FDI, there were, as at 2004, more than 35 investment incentive schemes in place across the country (Gelb and Black, 2004).

A key motivation for these efforts by the South African authorities hinges around a widely held but controversially substantiated notion that there is a technological externality to FDI. Commonly referred to in the literature as FDI spillover, its proponents have argued that domestic economies in general and their firms in particular stand to reap technological reward from the activities of foreign multinationals (MNCs) operating in their countries. Despite the intuitive appeal of this claim, empirical analyses to date have yielded mixed results (Crespo and Fontoura, 2007). To improve our understanding on what currently appears to be an impasse some analysts have called for more detailed investigations that involve for instance, adopting an analytical framework which incorporates spillover promoting/inhibiting specific national factors (Lipsey, 2002), as well as employing appropriate data, that is generally considered to be panel data with disaggregation at the firm level (Gorg and Greenway, 2001).

Past efforts at explaining the incidence of FDI spillover in South Africa have generally relied on aggregated country or industry level data to confirm its positive impact (Fedderke and Romm, 2006, Gelb and Black, 2004). However, it is now known that relying on results obtained with aggregated data at a macro as opposed to micro firm-level template may not provide an accurate understanding of FDI gains, especially if the observed positive impact at national or industry level also comes with negative distributional implications. For instance, it is quite possible that by virtue of location specific attributes such as agglomeration, productivity gains attributable to FDI at a more aggregative macro level only accrue to a subset of firms within the entire national population. Or even if all firms were to benefit, chances are also there that these benefits will not be evenly spread across board. A scenario of this sort presents a distributional distortion that in the views of Crespo and Fontoura (2007) calls for

research attention. In articulating their argument the authors made the following remark:

...although FDI may work as a convergence mechanism at the national level, if it produces significant gains in efficiency for domestic firms, it can also increase domestic inequalities at a regional level. This is a result that certainly justifies further research (Crespo and Fontoura, 2007: 417).

Another limitation with current evidence from South Africa is that to date there has been no visible attempt at accounting for factors that promote or inhibit spillover occurrence especially with respect to the role of environmental specificities that Lipsey recommended. Yet it is well known also that the South African economy, like those of other developing ones, is encumbered with many deficient characteristics, among which skilled manpower shortage occupies a pride of place. Indeed, as recently as 2009, a report carried on the website of Grant Thornton cited International Business Report as finding for the third consecutive time that skill shortage remains the greatest constraint to business growth in South Africa (Grant Thornton, 2009). There are also several Survey Reports produced by both local and international organisations that have documented the acuteness of manpower shortage in the economy.¹ As we shall see later in this paper, if theoretical predictions of the implications of skill shortage for FDI spillover are anything to go by, an investigation of the impact of foreign capital on productivity performances of South African firms would surely be a revealing exercise.

In the light of all these considerations, we are inclined to define research questions to be investigated in ways which depart from previous attempts as follows: (a) To what extent does FDI spillover rely on host economy's skill deficiency characteristic before it can be generated and appropriated? (b) Is there a regional dimension to the level of spillovers from multinationals to domestic firms? To address these issues, we estimate regression equations for a representative sample of South African manufacturing firms using information obtained from World Bank Enterprise Survey database. Our findings reveal that regardless of the presence of this environmentally imposed constraint, foreign firms are able to generate technological spillover for their host. Successful diffusion to domestic firms is however, mediated and severely circumscribed by the skill deficiency factor. Furthermore, support for the claim that level of FDI spillovers that diffuses to domestic plants relies on regional presence is weakly revealed in our evidence.

This paper is organised into six sections. We start with a review of relevant literature in Section 2, followed by motivation and specification of all hypothesised relationships in Section 3. In Section 4 relevant issues around

model specification are treated alongside data and variable construction before presenting results in Section 5. The final section summarises and presents the paper's concluding remarks.

SKILL CONSTRAINTS, AGGLOMERATION ECONOMIES AND TECHNOLOGICAL EXTERNALITY OF FDI DEBATE

The Basic Argument: Despite its recognition in early attempts to explore the impact of FDI on host country's economic performance, the productivity spillover dimension did not receive a formalised comprehensive theoretical treatment until the late 1970s when contributions from experts like Findlay (1978), Koizumi and Kopecky (1977) and Das (1987) among others began to appear in the literature.² In their various quests to explain the complex mechanism that generates the so-called "positive contagion" effect of foreign capital on host productivity, a very plausible but refutable proposition was made.

Assume as it is argued to be the case that foreign capitals of MNC subsidiaries embody some firm specific assets otherwise called technological advantages. Being backward offers the domestic firms in the FDI importing country an advantage to bring own technology level to those of their resident foreigners as long as they can capitalise on the now available opportunity to copy or learn from the advanced technology of MNCs. The importance of relative backwardness is very much emphasised as a key determinant of potentials to close the technology gap. Thus the lower the host's technology level relative to the foreigner's, the better the chances and magnitude of successful technology diffusion. In the final analysis, the model has prediction to the effect that the larger the host's stock of foreign capital relative to domestic ones the higher the rate of her technical progress.

After nearly four decades of empirical research, it is hard to find concrete evidence in support of this prediction. In fact available evidence seems to weigh heavily against it. In a fairly recent survey of the literature, Gorg and Greenway (2001) reported that most works failed to find positive spillover impact of FDI while evidences of negative spillover were even discovered in a good number of studies. With regards to studies in the survey that used firm-level panel data which is generally considered to be the appropriate technique of inquiry of this kind, only two out of a total of 16 found significant positive spillover effect. Five of these studies found negative impact while the rest could not establish any statistically significant relationship between FDI and domestic firms' productivities.

Local Environmental Conditions, Skill Shortages and Agglomeration: Attempts to make sense of these divergent results have seen critics

launch a two-pronged attack on both theoretical and empirical fronts. Those who grudge the theory argue that technological diffusion does not only depend on relative backwardness of FDI importer but also on a number of other host's economic characteristics. In what can be described as a non mainstream explanation Marin and Bell (2004) argue that certain aspects of the local environment that create constraints and opportunities for MNC subsidiaries do matter for FDI spillover occurrence. In their unconventional exposition, the authors present a framework which conceptualises a typical MNC subsidiary as a knowledge creating entity and not, according to conventional model, a passive knowledge transferring intermediary that simply receives knowledge initially created outside by its parent company and delivers it to beneficiaries in the host economy. In this view, if local environmental conditions like socio-political system, labour markets, skill structures and infrastructures are not supportive of the knowledge creation process, no spillover will be created let alone appropriated. A particularly striking aspect of their contribution lies in the message that it is what the MNC subsidiaries actually do in the host country as may be revealed in knowledge-creating and knowledge-accumulating activities as well as embeddedness in linkages with domestic firms that matter for spillover. Since these activities are essentially independently driven at local levels and not dictated or directed from headquarters we are reminded by the authors that the mere existence of MNC subsidiaries is not what is really important for technology to be generated and its value appropriated.

But while this brand of argument relates to the supply-side of spillover another paradigm as revealed in works on absorptive capacity focuses on demand side with similar conclusion that local environmental conditions like those mentioned above must be right before there can be incidence of spillover (Wang and Blomstrom 1992, Perez, 1997, Kinoshita, 2001, Hermes and Lensink, 2003). Also, Baskaran and Muchie (2009) suggest that weak national system of innovation is linked to low absorptive capability of technology spillover from FDI. They established possible relationships between the characteristics of a National System of Innovation (NSI) and their impact on FDI outcomes, particularly in developing countries. They employed a heuristic NSI-FDI conceptual framework linking the robustness of NSI to the benefits or lack of it from FDI and applied this to analyse descriptive data from selected developing economies; China, India, South Africa, Ghana, Ethiopia, Tanzania and Zambia (Baskaran and Muchie, 2009, Muchie and Baskaran, 2009).

The concept of absorptive capacity as argued in many of these contributions actually presupposes that spillover does not accrue in a vacuum. Rather, it is influenced by certain capacity related characteristics of the host. This capacity can be thought of in terms of a required threshold in the

level of development (Xu, 2000), especially as it relates to the skill quality of labour force (Blomstrom *et al.*, 1994, Kokko and Blomstrom, 1995). Whereas the requirement of relative backwardness presupposes the existence of some technology gaps between the MNCs and their hosts before spillover can materialise, the argument that a threshold in level of labour force's skill is needed suggests that this gap should not be too wide. When it is too wide, as may be captured in say, relatively highly unskilled (or acute shortage of skilled) labour force, the prospect of the host's firms engaging moderately skilled workforce with capacity to copy and adapt the technology of MNCs for their own purpose will be impaired. Conversely, a relatively moderate gap with sufficient assurance that the host's workforce is in possession of the right quantum of skill needed to internalise the foreigners' best practices will ensure successful diffusion. This argument would lead us logically to view differences in skill level of workforce or national absorptive capacities in general as one possible explanation for the divergent results that are revealed in the literature.

In the context of South Africa therefore, one may be tempted to suspect that her problem of inadequate supply of skilled manpower would definitely constitute an inhibiting force to the realisation of FDI spillover in the economy. But while this may be a significant problem in its own right there are also other environmental factors that either place significant demand on skill requirement as a key factor in FDI technology diffusion or raise the stake for investing in its supply. On the demand side, the capital intensive nature of FDI that the country has attracted over the past years places relatively enormous demand on highly skilled workforce before knowledge can be generated and transferred. As Figure 3 reveals for instance, the distribution of foreign firms is positively skewed in favour of the more capital intensive and skill demanding sectors like Motor Vehicle, Chemical & Allied Products, Electrical & Electronics and Machinery. On the supply side, it can be argued that the prevalence of such national calamities as crime and AIDS creates uncertainties and prevents medium and long-term commitment of firms by discouraging investment in training and development of staff. Despite her problem of skill shortage a recent World Bank Report reveals that relatively few firms in the country, in comparison with other countries like China and Brazil, have training programmes for their staff. About 45 per cent of firms interviewed had expressed concern over the impact of the AIDS epidemic and that this concern had a strong impact on their investment (Clarke *et al.*, 2005).

But recent development in the of analysis of skill factor as an element of absorptive capacity has shifted the focus beyond national level accounting to that of a sub-regional one and in the process draws attention to the possibility of a regional bias in FDI spillover effect. It is being claimed that its

occurrence may vary among the constituent regions of a nation depending on the skill characteristics of regional workforces. The implied hypothesis that we may expect to associate regions with high level of educational attainment or sufficient presence of skilled workforce with successful FDI technology adoption and those with low level or insufficient presence with limited success at best has been confirmed in some studies (Ponomareva, 2000, Yudaeva *et al.*, 2003).

Reinforcing the above allusion to regional distortion in spillover effect is the argument of those who model economic geography as a determinant of technology diffusion. According to this view, there are several reasons to expect that all regional constituents of a nation will not benefit in equal measures from the activities of MNCs. Some of these include: (a) Both demonstration effects and mobility of labour from foreign to domestic firms which constitute two key channels of technology transfer may be confined to local areas where MNCs are located; (b) Due to transport costs, vertical linkage that is also another source of technology diffusion may be bounded in space. Since all these factors operate in favour of those native firms with significant presence in or around the regions where MNCs are present the expectation follows that much of the technology that will diffuse to domestic firms will be confined to these regions. Several authors have pushed this argument beyond mere rhetoric by empirically showing that FDI spillover has a circumscribed regional dimension (Renato, *et al.*, 2007, Torlak, 2004, Girma, 2003, Girma and Wakelin, 2001).

With respect to the empirical evidence, the major issues that have arisen are centred on appropriateness of research design employed in many of the studies. For instance, the use of aggregate country or industry level data which appears to be popular with spillover empirical studies rather than firm level ones does not allow for detailed investigation by controlling for other factors (Gorg and Strobl, 2001). As further pointed out by Gorg and Greenway (2001), the notion of building empirical conclusions around cross-sectional as opposed to panel data evidence that is the case with many of the existing investigations does not allow the time variant nature of the studies to be captured. A final aspect of empirical inadequacy is implied in Lipsey's recent suggestion that a detailed analysis of the different circumstances and policies of countries, industries and firms that promote or obstruct spillovers is needed for better understanding of how FDI impacts on productivity (Lipsey, 2002).

South Africa-based Studies: A literature survey of FDI spillover studies that have so far been conducted for the South African economy reveals that the emerging body of evidence still has much to learn from many aspects of the critics' arguments mentioned above. For instance, in Fedderke and Romm (2006), spillover was modelled in a growth accounting framework

using aggregated data at national level to confirm its positive impact. Gelb and Black (2004) represents another attempt at accounting for the incidence of spillover by using statistical averages at sector level to shed some light on MNC subsidiaries' expenditure on training and human capital development in South Africa. As these studies neither accounted for the role of environmental specificities such as skill constraint factor nor employed firm level data as we did in this paper, the departure and relevance of our study has hopefully been well established.

MAIN HYPOTHESES

All the hypotheses investigated are inspired by the basic theoretical proposition that foreign capital generates technological returns for the host economy and empirical convention which captures this argument in terms of some qualified pattern of relationship between proxies for foreign presence and productivity performances in the economy.

Following Aitken and Harris (1999), the productivity spillover of FDI can be measured at both plant and industry levels. In the former case, if foreign capital embodies advanced technology we should, other things being equal, associate establishments with foreign presence with significant productivity gains. But all things are not equal in a skill-constrained economy. It is arguable that as a result of skill shortage, enterprises' chances of engaging employees with the right kind of skills needed to internalise the foreign technology will be constrained. However, we argue here that inability to attract skilled workforce will hardly constitute a significant problem for the MNCs. Because of their better incentives, they can price out their domestic counterparts from the marginal skilled labour market that exists thereby equipping own plants with capable hands.³ We have come to know as well that when skill shortage is the problem, MNCs do provide training for employees in order to raise their level of competence to that required by them. Hence, our first hypothesis will not depart from conventional wisdom which says:

Hypothesis 1: Plant level foreign presence is positively related to productivity performance and those with more foreign equity participation should exhibit higher productivity performances than their comparable domestic counterparts.

In the latter case, economists have proffered several reasons why the presence of foreign technology in an industry should have a positive contagion effect on domestic technology of the industry. First, the demonstration effect makes it possible for domestic plants to imitate or copy the technological

practices of their foreign competitors (Wang and Blomstrom, 1992, Barrios and Strobl, 2002). Second, workers from MNC subsidiaries can move to local companies and in effect deploy the skill and knowledge they acquired in the former for the latter's benefit (Glass and Saggi, 2002). Third, vertical linkages by foreign firms with local suppliers or customers also afford the natives the opportunity to learn the best practices.

All these various channels of technological leakages have implicit assumptions that learning, on the part of domestic firms' employees, is concurrently and effortlessly taking place. But this may not be so if by virtue of skill shortage in the economy these plants are unable to engage the right calibre of workers. This is likely to be so especially if the MNCs completely absorb all of the marginal skilled manpower that exists in the economy and jealously guard them from leaving to work for domestic competitors. Employees with inadequate skills will almost certainly have difficulty copying or imitating the advanced technological practices of MNCs. In similar manner domestic suppliers/customers with poorly trained staff who interact with foreign companies may practically learn little or nothing from their interaction.⁴ All these blur the chances that technology will get transmitted through the previously discussed channels. Hence the question of how well externalised foreign knowledge gets diffused to the locals is now a question of how well the locals are prepared to make the right kind of investment in human capital in order to increase their absorptive capacity. Those who invest well enough are more likely to do a better job attracting capable hands and absorbing foreign technology than their counterparts, other things being equal. Hence the second hypothesis for investigation can be stated thus:

Hypothesis 2: Domestic firms with relatively highly skilled workforce are more successful in absorbing technology spillover from resident MNC subsidiaries.

Finally, it is understandable to have some people argue that levels of technology that do spillover to domestic establishments have a regional tone. This is simply because by virtue of possession of certain competitive attributes some regions are relatively better at attracting manufacturing activities to their areas. These attributes as may be revealed in the presence of better economic infrastructures or as the New Economic Geography literature would have us believe, access to certain external economies confer some significant economic advantages on the locals. For instance, being close to regional clusters may facilitate access to a common pool of skilled labour or enhance knowledge linkages among management staff. Linkages with suppliers/distributors are also other sources of external economies that come with agglomeration. If foreign firms are driven to locate in this type of region, as it is likely, then for the simple reason that proximity

enhances the effectiveness of technology diffusion channels we may expect to observe domestic firms in the region absorbing more of the spillover returns than their counterparts elsewhere.⁵ For instance, effective capture of the diffusion benefits of demonstrating a new product or production process favours those that are closer to the place where such demonstration takes place. Also, if a highly skilled MNC employee decides to leave and transfer the knowledge he has gained to domestic firms it is the ones located nearby that stand the better chance of engaging his service. Furthermore, linkages with local suppliers and distributors may be limited to the region because of transportation cost. The hypothesis therefore is that:

Hypothesis 3: The level of spillover absorbed by domestic establishments is greater for those located in regions with more foreign presence.

MODEL SPECIFICATION, DATA AND VARIABLE CONSTRUCTION

The Model: The validity or otherwise of these hypotheses were tested by specifying and implementing an augmented Cobb–Douglas production function incorporating spillover and other productivity enhancing variables for a sample of South African manufacturing firms. We also included as controls other environmental constraints that appear to be of equal importance as skill shortage. Generally, the model estimated is of the form:

$$Q_{ij} = C + \beta_1 X_{ij} + \beta_2 Pe_{ij} + \beta_3 Ec_{ij} + \beta_4 fpp_{ij} + \beta_5 fpind_j + \beta_6 aggl_{ji} + e_{ij} \quad (1)$$

where:

- Q_{ij} = output for plant i in industry j
- X_{ij} = vector of production input for firm i in industry j
- Pe_{ij} = vector of other productivity enhancers that include human capital/skilled labour
- Ec_{ij} = measure of other environmental constraints
- fpp_{ij} = measure of foreign presence at plant level
- $fpind_j$ = measure of foreign presence at industry level
- $\beta_6 aggl_{ji}$ = measure of foreign presence at industry level in regional location.
- e_{ij} = usual error term

For impact on domestic firms' estimations both dependent and control variables only reflect data for domestic firms as required by hypotheses 2 and 3.

In the above specification, output is assumed to be a function of not only measures of input variables but also different measures of spillover,

environmental constraints, agglomeration and other productivity influencing factors. The coefficients of variables of interest (spillover) shall be interpreted as evidence of the impact of foreign presence, which may confirm or refute our hypotheses. Data for the equation (1) which represents the basic model for estimating several regressions in accordance with the dictates of our hypotheses have been expressed in the log-liner form and Ordinary Least Square technique is employed all through. The data and preliminary evidence arising from casual analyses that were performed are discussed next.

Data and Preliminary Evidence: Data for the investigation come primarily from The World Bank Survey of Enterprise in South Africa. The said Survey was conducted and completed for about 800 establishments between January and December 2004. A stratified random sampling methodology that generated 603 manufacturing establishments from the 800 that were sampled was followed. The framework of the said sampling technique was carefully designed to generate large enough sample size for a given industry. Level of precision with respect to both estimates of population proportion and mean of log of sales at industry level was fixed at 7.5 per cent for 90 per cent confidence interval. This simply suggests that except in 10 per cent of the cases there is a guarantee that the population parameter will be within the 7.5 per cent range of the observed sample estimate.⁶

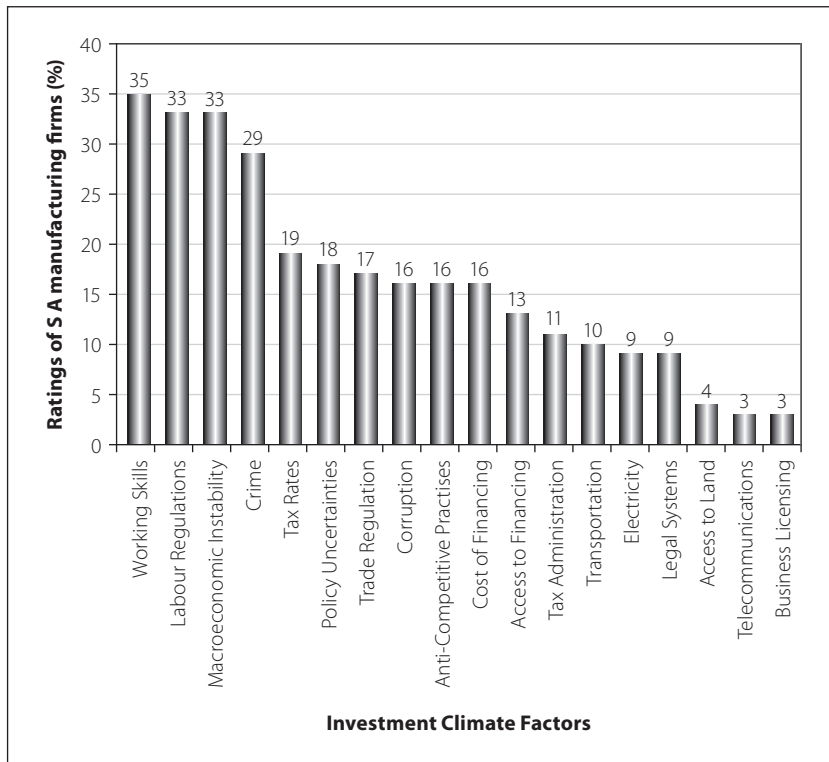
The unit of analysis was the establishment defined as a factory, store or service outlet with own accounting identity and formally registered with the Department of Trade and Industry.⁷ For the purpose of this research the words establishment, firm and plant will be used interchangeably to refer to this conception. The Survey which covers a three year period from 2000 to 2002 is cross-sectional meaning that we are constrained into using cross-sectional data in this analysis. Plants included in the exercise are mainly those with employment figures of ten or more, although there are few cases of microenterprises where staff strengths are below ten in number. The sectoral orientation of the manufacturing establishments that are the focus of this analysis corresponds to the ISIC revision 3.1 and only plants from eleven sectors that include Garment & Textile, Paper, Printing & Publishing, Food & Beverages, Rubber & Plastic, Electrical & Electronics, Wood & Carpentry, Chemical & Allied Products, Machinery, Furniture, Motor Vehicle and Other Manufacturing are taken for the investigation. After dealing with the problem of imperfect data we were left with 455 and 302 observations respectively for plant level and domestic level foreign presence estimations. Summary statistics with respect to variables used are provided in Table 1.

From the preliminary analysis of sampled evidence as revealed in the data we are able to confirm the validity of some of our underlining assumptions in this investigation. For instance, with respect to skills shortage, besides being the one environmental factor perceived by most South

African manufacturing establishments as constituting the most serious obstacle to the smooth operation of their businesses, the problem is also found to have revealed the economy, as relatively uncompetitive among a comparator group of economies. A cursory look at Figures 1 and 2 shows this more clearly. It is easy to observe from Figure 1 that more plants rated Workers' Skills as a Major or Very Severe Constraint to doing business in South Africa than any other investment climate constraint. Further, a multi-country comparison of plants identifying Labour Skill Level as a Major Constraint to their operation as given in Figure 2 also shows that nowhere except Brazil are more plants dissatisfied than South Africa.

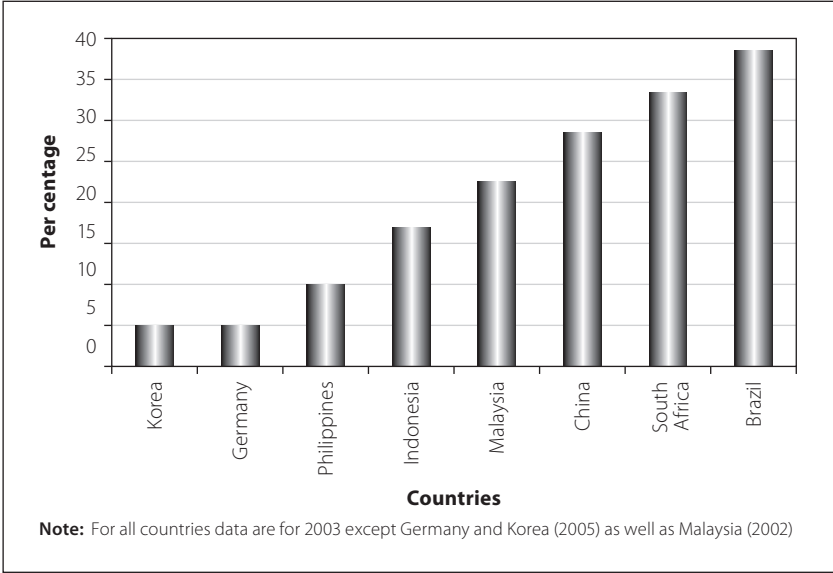
It also appears that the two phenomena of capital intensity and plant productivity are positively associated with the incidence of foreign presence. In Figure 3 where distribution of foreign firms alongside sectoral line is given, it can be seen that two of the highly capital intensive sectors (Motor Vehicle and Chemical & Allied Products) reveal the highest levels of foreign penetration whereas the more labour intensive ones (Furniture and Wood & Carpentry Sectors) reveal some of the lowest levels. This is

Figure 1 Percentage of South African Manufacturing Firms in 2002 Rating Investment Climate Factors as Major or Very Severe Constraints



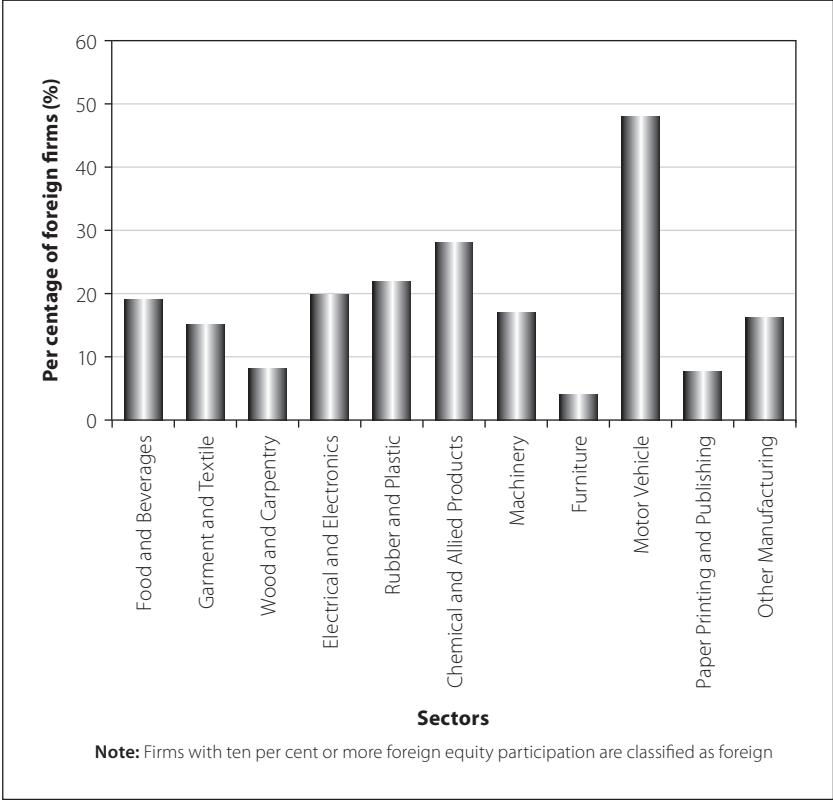
Source World Bank Enterprise Surveys

Figure 2 Percentage of Firms in Each Country Identifying Labour Skill Level as a Major Constraint



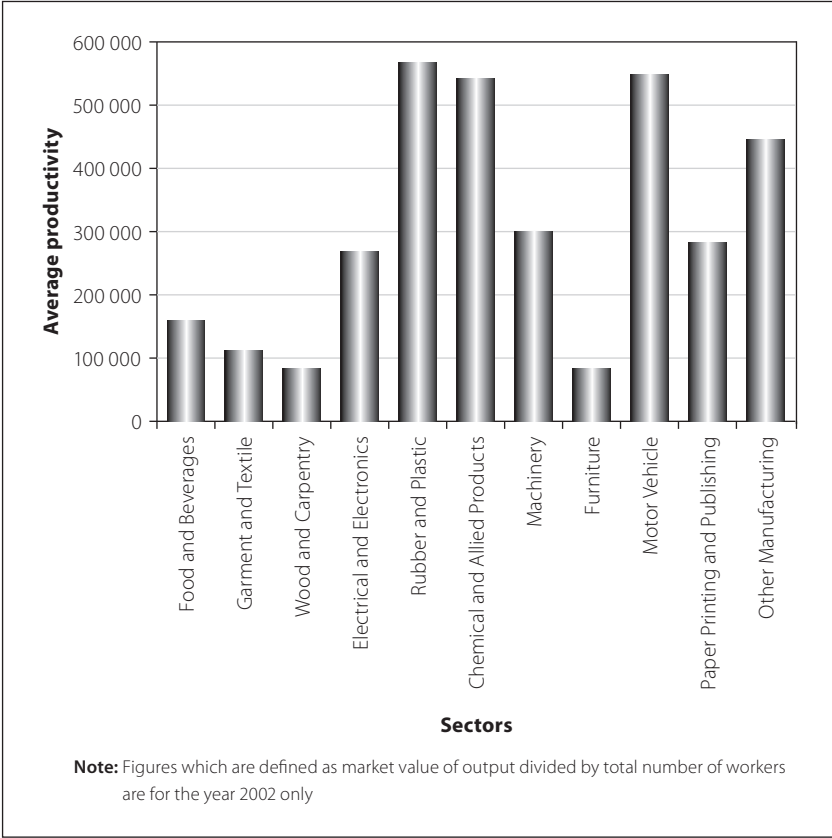
Source <http://www.enterprisesurveys.org/>

Figure 3 Percentage Number of Foreign Firms in Each Sector



Source <http://www.enterprisesurveys.org/>

Figure 4 Average Productivity in Each Sector



consistent with the finding in Fedderke and Romm (2006). Furthermore as contained in Figure 4 where the productivity dimension of this relationship is shown, it seems that there is a positive association between sector-level foreign presence and productivity: The three most productive sectors (Rubber & Plastic, Motor Vehicle and Chemical & Allied Products) are the sectors where foreign presence is most pronounced. On the other side, the lowest productivity performance is observed in the Furniture Sector with the least level of foreign penetration.⁸

Variable Construction: Following standard practice the dependent variable is defined as the value of output. As measures of input factors, three variables have been included in the estimation. These are capital, labour and material. Capital is generated using information on plant fixed assets. It is calculated as the value of rent paid for machinery and equipment or value of depreciation incurred on owned assets. Labour is as usual defined in terms of the average number of workers (temporary and permanent).

Other productivity influencing variables that the literature suggests can be thought of as comprising various forms of knowledge factors that

confer marketplace competitive advantage on firms over their rivals. Such knowledge can be acquired either through exposure gained as a result of exporting activities or through transferred technology from investment in plant and machinery. It could also become incumbent on an organisation because such organisation is driven by employees with more sophisticated skill background. The inclusion of this variable is very central to our analysis. These different sources have been captured by three different measures of productivity enhancing variables, viz, export intensity, investment in plant and machinery, and human capital. Export intensity is defined as the per centage of establishment's sales exported directly. We measured investment in plant and machinery as the ratio of plant's new expenditure on machinery and equipment to output. Finally, proceeding from the logic that skilled workers attract relatively high wage compensation and that we should naturally expect the two events (skill and high wage bill) to coincide, human capital has been captured as the average wage bill of the firm. It is expressed as the ratio of a firm's wages to total number of employees. All these measures like measures of production input are expected to show positive associations with productivities.

The other environment specific constraints which appear to be of equal importance as skill in the data that were controlled for are: Macro economic instability, labour regulation and crime. From the information provided in Figure 1 at least 29 per cent of firms interviewed rated each of these factors as Major Obstacle. Three variables captured in categorical terms *ecm*, *ecl*, and *ecc* proxy for the different influences of macroeconomic instability, labour regulation and crime respectively. A value of 1 was assigned if respondents considered any of the three factors a severe or very severe constraint and 0 otherwise. All these variables should be negatively related to productivity.

With respect to the spillover variables, foreign presence at plant level (*fpp*) is defined as the level of foreign participation or per centage of equity share capital owned by foreigners in a plant. The value varies between 0 and 100 per cent. Its coefficient is expected to turn up with a positive sign. The industry level version capturing the degree of foreign penetration in an industry (*fpind*) is measured by the share of foreign firms' employment in industry employment.⁹ It can be gleaned from our previous argument in hypothesis 2 that this variable will not ordinarily impact positively on domestic firms productivities unless it is adjusted for skill influence. Consequently it is interacted with the human capital factor to produce another variable termed *fpind*human k*. Unlike the expectation we have for the impact of its less refined counterpart this one should positively associate with productivity. Finally, to capture the influence of regional concentration of foreign firms we introduced the variable termed *agglo* which is defined as the proportion of sectoral employment accounted for by foreign firms in

a region. Consistent with its motivation, if regional agglomeration matters for FDI Spillover, its coefficient should be positive.

Table 1 Summary Statistics

Variables	Observation	Mean	Std. Dev
output	455	2.66	1.79
output (dmstc)	302	3.01	2.56
k (capital)	455	2.97	1.68
l (labour)	455	3.34	0.33
m (material)	455	4.67	1.50
human k	455	2.82	1.97
invest in mach	455	0.49	0.67
export Intensity	455	-0.45	0.37
ecl	455	0.18	0.25
ecm	455	0.15	0.30
ecc	455	0.37	0.44
spillover (fpind)	455	1.43	1.14
spillover (fpp)	455	0.96	0.12
agglo	455	0.39	1.74

RESULTS

Results of regressions estimated to address issues raised above are presented in Tables 2, 3 and 4. In the estimation that was carried out heteroscedasticity problem was dealt with by estimating variance-covariance matrices along the line suggested by White. From the output of all three regressions, the Ramsey RESET set assures us that misspecification should not be a major worry. Having said these, we can now proceed to comment on the results. Regression output for the own plant technology transfer (i.e. plant level channel) is first presented in Table 2 before estimates for possible industry wide spillover to domestic firms are presented in Table 3

(industry level channel). Table 4 reports the verdict for the regional effect. For all specifications the input variables are statistically significant and all turned up with expected signs.

Beginning with Table 2, results indicate that our variable of interest (*spillover (fpp)*) is positively signed and statistically significant at one per cent level. This suggests that domestic firms with foreign equity participation benefit from their cross border association. A ten-percentage point increase in foreign ownership increases firm productivity by 0.4 per cent. In other words, for an establishment where foreign participation increased from zero to ten per cent, productivity performance gains would be 0.4 per cent higher than for comparable domestic plants. We interpret this to mean a confirmation of our first hypothesis (hypothesis 1) which has also been affirmed in a previous study (Aitken and Harrison, 1999). The fact that sampled firms are reaping efficiency rewards from the presence of foreign assets in their equity mix is confirmative of the widely held, but controversially substantiated view that there is a technological spillover return to FDI.¹⁰

Table 2 Foreign Direct Investment Spillover (Own-Plant Effect)

Variables	Plant Level
spillover(fpp)	0.04 (2.53)***
k (capital)	0.26 (2.58)***
l (labour)	0.11 (8.23)***
m (material)	0.19 (1.89)*
human k	0.12 (2.63)***
invest in mach	0.01 (1.74)*
export Intensity	-0.08 (1.80)*
ecm	0.96 (1.42)
ecl	-1.84 (1.58)
ecc	-1.01 (1.88)*
Adjusted R ²	0.78
White Test	2.77***
Ramsey RESET	1.14
Observations	455
Notes: (1) The t-statistics are in parentheses; (2) Significant at ***1 per cent, **5 per cent and *10 per cent	

Moving further to Table 3 we find that the coefficient of the spillover variable through the industry channel, though positive, is insignificant. This suggests that the positive impact of foreign capital on own plant productivity that was confirmed in hypothesis 1 above and would under normal circumstances be expected to diffuse to domestic firms effortlessly could not be confirmed. Failure to establish this sort of industry wide spread of foreign technology that some previous studies have established (Buckley *et al.*, 2007, Sinani and Meyer, 2004) is consistent in part, with the motivation of our hypothesis 2. That is, in an environment where the requisite skills needed to facilitate the diffusion process is in short supply like South Africa, domestic enterprises are, to borrow Abramovitz's term, 'socially incapable' of internalising the externalised technological know-how of their foreign counterparts. It does appear that in general their inability to compete with foreign firms for the engagement of skilled employees have left them with the only option of relying on workforces that practically lack capacities to learn, copy, imitate and adapt the supposedly advanced practices of the foreign companies for their plants use.

Table 3 Foreign Direct Investment Spillover (Domestic Plant Effect)

Variables	Industry Level
<i>spillover (fpind)</i>	0.01 (1.53)
<i>spillover (fpind)*human k</i>	0.08 (1.96)**
<i>k (capital)</i>	0.02 (2.09)**
<i>l (labour)</i>	0.35 (8.03)***
<i>m (material)</i>	0.22 (2.11)**
<i>human k</i>	0.01 (1.09)
<i>invest in mach</i>	0.01 (1.38)
<i>export Intensity</i>	-0.27 (0.40)
<i>ecm</i>	1.74 (0.65)
<i>ecl</i>	1.03 (0.08)
<i>ecc</i>	-0.12 (1.81)*
<i>Adjusted R²</i>	0.72
<i>White Test</i>	2.19**
<i>Ramsey RESET</i>	0.11
<i>Observations</i>	302
Notes: (1.) The <i>t</i> -statistics are in parentheses; (2) Significant at ***1 per cent, **5 per cent and *10 per cent	

To prove legitimacy of the above conclusion the argument put forward in hypothesis 2 further suggests that all domestic firms may not be equally unable to attract moderately skilled workforce that can help facilitate the technology appropriation process. As long as some of them are ready to make the right investment in human capital accumulation they should be able to increase their capacities to absorb and it follows that some amount of technology may diffuse to the locals through this group of firms. Thus if we can refine our analysis to take account of this fact we may observe a positive coefficient for the spillover variable. It turns out that after interacting the same spillover variable with human capital proxy the coefficient of the resulting variable (*spillover*human k*) is positive and significant at five per cent level suggesting that the diffusion process truly has a skill accent. Basically, what this finding confirms

Table 4 Foreign Direct Investment Spillover (Regional Effect)

Variables	Industry Level
Agglo	0.02 (1.71)*
<i>k (capital)</i>	0.09 (1.99)**
<i>l (labour)</i>	0.15 (4.00)***
<i>m (material)</i>	0.54 (4.51)***
<i>human k</i>	0.01 (0.74)
<i>invest in mach</i>	0.01 (1.00)
<i>export Intensity</i>	-0.25 (0.90)
ecm	1.12 (0.32)
ecl	0.9 (1.44)
ecc	-0.12(1.91)*
Adjusted R^2	0.73
White Test	1.89**
Ramsey RESET	0.09
Observations	302
Notes: (1) The t-statistics are in parentheses; (2) Significant at ***1 per cent, **5 per cent and *10 per cent	

is that technology of resident MNCs does not spread effortlessly to domestic firms. A minimum level of skill capacity is required before successful absorption can take place. Thus our suspicion that skill matters for the spread of technology to domestic firms and that those with relatively more sophisticated workforce will be more successful in the absorption process is borne out in evidence.

Finally, results from our exploration of the possibility of a regional dimension to the level of appropriated spillover by domestic firms as revealed in Table 4 lend some faint support to our claim. The evidence is weakly present as estimated coefficient for the variable of interest (*agglom*) shows up with a positive value that is significant at barely ten per cent.

CONCLUSIONS

Despite the nearly half a century old attempt to understand and explain the phenomenon of FDI spillover, the debate on whether or not host economies do benefit technologically from the activities of MNCs is still far from over. Precisely with respect to the role of country specific environmental factors that promote or inhibit FDI related technology transfer as well as the influence of regional factor evidence is especially lacking for South Africa. We have attempted in this paper to produce insight into this challenging problem by investigating the issues using firm-level evidence.

Results from estimated regressions reveal that, despite the problem of skill supply deficit that the business environment imposes, firms with foreign equity participation are able to generate technological spillover for their host. Successful diffusion to domestic firms is, however, mediated and significantly circumscribed by the skill factor. Furthermore, evidence in support of the claim that level of FDI spillover relies on regional presence is present, though further research is needed to shed helpful insights that may be fed into policy learning.

From both analytical and policy perspectives these findings are instructive in the sense that they underscore the importance of unbundling spillover into its constituent channels of manifestation. At least in the context of South Africa, we now know that all firms are not equally inhibited by the environmentally imposed skill shortage constraint. Foreign firms are by virtue of their endowment able to get around it and deliver on their potentials. It is the domestic firms that are paying heavy technological price as a result. But whether or not this suggests a need for policy initiative to help domestic firms develop capacity to absorb spillover from MNCs should not be the issue. Rather what should concern us is finding how to increase the supply of human capital into the economy in general.

In the final analysis though, the message needs not be lost that the strength of our claim on the basis of revealed evidence is obviously weakened by limitations of the data we have used as well as econometric technique adopted. Robustness of cross-sectional based findings, we all know too well, is circumscribed by methodological inability to deal with such key challenges as endogeneity of factors, opportunistic investment behaviour and time variance. We cannot but admit being humbled by these considerations to say that evidence presented is at best suggestive and more sophisticated approaches especially the use of panel data would be required to take this further.

NOTES

- 1 Some of these Reports include: The National Enterprise Survey (1998); The World Bank Large Manufacturing Firm Survey (1999); The World Bank Small, Medium and Micro Enterprise Firm Survey (1999); The Human Sciences Research Council (HSRC) Survey of Skills (2003). For a review, see Reza, C. D. (2007)
- 2 MacDougall (1960) is widely recognised as the first author to explicitly acknowledge technology spillover as one of the potential benefits from FDI in his analysis of the welfare effects of foreign investment. Other early authors who followed in the direction of MacDougall to argue that productivity spillover is among the list of many positive impact of FDI were Corden (1967) and Caves (1971). In describing the works of these authors Blomstrom and Koko (1997, p. 10) noted: "The common aim of these studies was to identify the various costs and benefits of FDI and spillovers were discussed together with several other indirect effects that influence the welfare assessment, such as those arising from the impact of FDI on government revenue, tax policies, terms of trade, and the balance of payments. The fact that spillovers were taken into account was generally motivated by empirical evidence from case studies rather than by comprehensive theoretical arguments".
- 3 A number of authors have argued that MNCs pay higher wages than their domestic counterparts in order to attract and retain high quality staff (Lipsey and Sjöholm, 2004; Sinani and Meyer, 2004; Glass and Saggi 2002; Fosuri *et al.*, 2001; Aitken *et al.*, 1997).
- 4 This argument is only relevant if we are interested in vertical linkages which will involve a specification of inter-industry spillover model. In the present circumstance, our hypothesis and econometric specification are restricted only to intra-industry analysis.
- 5 According to one recent study economic activities in South Africa are geographically unequally distributed and concentrated with an estimated 70 per cent of GDP being produced in only 20 per cent of places (Krugell *et al.*, 2005). Another work further finds that the phenomenon of industry concentration in certain provinces of the country is explained by provincial endowment in some aspects of economic attributes that are mentioned here. For instance, attributes such education, skill levels and road transport infrastructure density are shown to be important in the cases of Gauteng and KwaZulu-Natal while education and skill levels explains the case of the Western Cape Province (Naude, C. M. 2003).
- 6 See: <https://www.enterprisesurveys.org/>.

- 7 More that 80 per cent of respondents claim their establishments are single entities with no other separately owned operating establishments elsewhere in the country.
- 8 While it is tempting to argue that there is a prima-facie evidence, on the basis of this revelation, that foreign firms tend to be more productive than their domestic counterparts, the possibility that these firms (foreign) could just be engaging in opportunistic behaviours by investing only in the more productive sectors weakens the appeal of such argument.
- 9 Foreign firms are defined as firms with 10 per cent or more foreign equity participation.
- 10 This finding should however be interpreted with caution as decisions to invest in an economy by foreigners are sometimes driven by some perceived productivity potentials in a targeted establishment. It is therefore possible that the revealed performance superiority of these foreign owned enterprises is picking up this exogenous influence.

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A Consensual Approach to Domain-Partitioning of a Cancer Data Sample Space

Lessons from Tanzania

Kassim S. Mwitondi and Khamza K. Maunda

SUMMARY

Interest in the patterns and predictability of various types of cancer has been steadily growing over the years (e.g. Steliarova-Foucher *et al.*, 2004). However, comparative studies on geo-ethnic grounds (particularly Africa-specific) have been quite limited. Further, the influence of commonly known predisposing factors on various types of cancer has mainly been studied using conventional statistical analysis approaches which, typically, make assumptions about the underlying data distributions. We critically examine the common methods used in studying cancer predisposing factors and propose a novel triangular approach to detecting patterns in data samples. Three samples of cervix cancer, conjunctival cancer and Kaposi's sarcoma, collected from various regions in the United Republic of Tanzania, are subjected to techniques for graphical visualisation (GDV), association rules (AR) and dimensional reduction (DR). We uncover interesting patterns in the distribution of the three cancer types hinging on Tanzania's basic cultural attributes and geographical diversity.

The results are analysed in a multi-disciplinary context; presenting an unprecedented approach to addressing cancer-related research issues. Our findings show that the triangular approach is capable of uncovering subtle cultural-driven relationships among data attributes. The findings present a rigorous basis for assessing and evaluating the impact of predisposing factors on the three types of cancer hence providing some useful guidelines into informed intervention, prevention and treatment of the diseases. On the basis of the results from the analysis, the paper makes recommendations as to how to structure future cancer studies in areas of similar geo-ethnic features. The triangular approach to extracting knowledge from data provides good insights into avoiding knowledge-masking effects and highlights the need for formulating and designing a prototype model for updatable cancer-related data sources and storages aimed at connecting cancer registries across the African continent and beyond.

INTRODUCTION

Interest in studying comparative patterns of various types of cancer has been steadily growing over the years (Steliarova-Foucher *et al.*, 2004, Ames *et al.*, 1995). Whereas cancer has been widely studied and results documented in the developed world, comparative studies on geo-ethnic grounds, particularly Africa-specific, have been rare and limited in scope. Recent initiatives include Mbulaiteye *et al.*, (2006) who carried out a cancer risk study among HIV/AIDS victims in Uganda. The influence of commonly known predisposing factors on various types of cancer has mainly been studied using conventional statistical analysis approaches which, typically, make assumptions on the underlying data distributions. In this study we critically examine the common methods used in studying cancer predisposing factors and propose a novel triangular approach to detecting patterns in data samples. Three samples of cervix cancer, conjunctival cancer and Kaposi's sarcoma, collected from various regions in the United Republic of Tanzania, are subjected to techniques for graphical visualisation (GDV), association rules (AR) and dimensional reduction (DR). We uncover interesting patterns in the distribution of the three cancer types hinging on Tanzania's basic cultural attributes and geographical diversity.

The paper seeks to answer the general question as to whether the provided data attributes lead to any informative cancer patterns on a geo-ethnic basis – that is: *Is there empirical evidence of geo-ethnic inter-dependency between the three types of cancer and the collected data attributes?* Validity of the questions lies in its potential for yielding useful diagnostic information. The study is based on samples of cervix cancer, conjunctival cancer and Kaposi's sarcoma – all well-known HIV defining cancers (Mbulaiteye *et al.*, 2006) – and their analyses seek to contribute to knowledge sources on the homogeneity/heterogeneity of the various types of cancer on geographical and ethno-cultural bases. Findings from the study are meant to strengthen and enhance comparability of the geo-demographic patterns of the diseases' occurrence in order to determine the efficacy of their prediction across geographical and ethno-cultural lines. It is expected that drawing conclusions from multiple analytical approaches – graphical visualisation (GDV), association rules (AR) and dimensional reduction (DR) – and comparing the results in time and space may help in detecting potential shifts in concepts, definitions and the baseline behaviour of various types of cancer. This type of multi-disciplinary approach to cancer studies has never been used before.

Using databases gathered from five continents, Kamangar *et al.*, (2006) were able to explain variations in the global cancer patterns through a complex relationship involving cancer risk factors on the one hand and other factors such as individual behaviour, socio-cultural beliefs, socio-economic

conditions as well as health care systems on the other. However, African statistics for cancer predisposing factors are low and rather fragmented (Parkin *et al.*, 2005).

Thus, the motivation of this study is two-fold. Firstly, there is a pressing need to carry out a thorough study of cancer predisposing factors across the continent. Focusing on a geographically and culturally diverse United Republic of Tanzania would positively contribute to knowledge of cancer patterns not only in the country but also in other places across the globe. Secondly, the influence of commonly known predisposing factors on various types of cancer has mainly been studied using conventional statistical analysis methods; typically, making assumptions on the underlying data distributions. Although non-parametric methods have also been adopted in studies, it is worth noting that results from non-parametric approaches are often susceptible to variations due to different types of randomness arising from, mainly, training, validation and test data (Mwitondi, 2003). Consequently, it is imperative to develop robust approaches that are resistant to potential variations.

The paper is organised as follows. An introduction is provided in Section 1 in which the research question, study objectives and motivation are outlined. Section 2 provides a literature review on both the theoretical and practical aspects of cancer studies followed by the methodology in Section 3 in which the data attributes are described. The section also provides a theoretical intuition into cancer data modelling as well as a full description of our proposed triangular consensus-searching approach. Discussions of the main results are given in Section 4 followed by concluding remarks and potential future directions in Section 5.

LITERATURE REVIEW

Different forms of cancer have been widely studied and documented in various studies across the world. In particular, comparability of predisposing factors for various types of cancer among different geographical and ethnic groups across the globe has been an on-going research theme for quite some time (Ames *et al.*, 1995). Meng *et al.*, (1997) investigated ethnic differences and factors relating to breast cancer among ethnic Filipinos, Hawaiians, Japanese, Chinese and Caucasian women and found that the ethnic Filipinos and Hawaiians had a significantly higher risk of dying within five years than the Japanese or Chinese. Parkin *et al.*, (2005) explored the geographical variation of incidence, mortality and prevalence of 26 different types of cancer and uncovered some striking patterns. Parkin (1998) reported that cervix cancer was more common in developing

countries; accounting for 78 per cent of the global cervix cancer cases and accounting for about 15 per cent of all female cancers whereas in the developed countries it accounted for only 4.4 per cent of all new cancers. Clifford *et al.*, (2003) investigated regional variations in the contribution made by different human papilloma (HPV) types to invasive cervical cancer on the basis of 85 regional and histological studies across Africa, Asia Europe, North America, Australia, South and Central America. Their African sample consisted of a total of six studies (7 per cent of the total) in Algeria, Benin, Guinea, Mali, Morocco, Senegal, South Africa, Tanzania and Uganda on detected a total of 609 cases. The analysis which was based on unconditional multiple logistic regression yielded a final model identifying sources of variation as geographical and histological. Regional and histological prevalence of HPV in cervical cancer worldwide revealed that HPV occurred 88.8 per cent in Africa, 83.1 per cent in Asia where 28 studies were carried out and 3,091 cases observed, 85.9 per cent in Europe where 32 studies were carried out and resulted into 3,336 cases. The corresponding statistics for North America and Australia were 87.5 per cent, 13 studies and 1,562 cases and those for South and Central America were 87.7 per cent, 12 studies and 1,460 cases. The design of the foregoing study makes its results quite likely to be sample dependent and under such circumstances, repeated sampling and renewed analyses are usually the available choice (Rubin *et al.*, 2002).

Unlike in the foregoing studies, this paper provides a comparative study of cervix cancer and Kaposi's sarcoma in the United Republic of Tanzania. In comparison with the rest of the world, cancer studies on the African continent have been rare and limited in scope. One recent study by Mbulaiteye *et al.*, (2006) investigated the risk of cancer among HIV/AIDS victims in Uganda over the period October 1988 to December 2002 and found, not surprisingly, a high proportion of AIDS-defining cancers such as Kaposi's sarcoma, cervical cancer and conjunctival carcinoma. Further, a number of general beliefs in cancer studies across the globe still require clear explanation from empirical studies. For instance, Waller *et al.*, (2004) highlight a number of issues relating to the UK public perceptions of cervical cancer especially with regard to the role of a sexually transmitted virus in its etiology.

Analyses of data collected from across the United Republic of Tanzania – one of the world's largest countries covering approximately 950,000 km² (or 590,320 square miles) – are expected to extend the scope of the foregoing approaches to cancer studies. The study investigates the interactions of socio-economic and cultural data attributes with respect to selected HIV-defining cancers. It is expected that an analytical look at patterns formed by the joint interaction of these factors, will uncover and help address other cancer-related issues. A detailed description of the study methodology is provided below.

RESEARCH METHODOLOGY

This section outlines the methods adopted in this study and its study of philosophy. It provides an account of the study environment, data description as well as briefly reviewing some of the methods and tools which have been used in studying the three types of cancer. The section also provides a theoretical intuition into the rationale of applying the proposed approach.

DESCRIPTION OF THE DATA ATTRIBUTES

Data for this study were obtained from the cancer registry of the Dar Es Salaam Ocean Road Cancer Institute (ORCI) in four different batches collected over a one-year period, January to December 2005. The data, 1,084

Table 1 Data Attributes for Kaposi’s Sarcoma, Cervix and Conjunctival Cancer

Variable	Variable type and description
Gender	Binary (Male/Female)
Age	Numeric: Patient’s age
Religion	Binary (Muslim/Christian)
Occupation	Categorical (9 different levels)
Smoking	Categorical (Current, Former Smoker or Never Smoked)
Region	Tanzanians geographical regions
Type	Categorical Squamous cell carcinoma of cervix Kaposi Sarcoma Squamous cell carcinoma of the conjunctiva
Topography	Categorical: Coded primary site of cancer C53.9 – Cervix (X) C44.8 – Generalised Skin (S) C06.9 – Oral Mucosa – (M) C44.8 and C06.9 – (P)
Extent	Categorical Regions 1, 2 and 3 (R1/R2/R3) Not Applicable (NA) Localised (LC) Unknown
Stage	Ordinal (8 levels plus Unkown)
HIV	Categorical: Patient’s HIV status Reactive (RX) Non-reactive (NR) Unknown, NOS (UN)

Source ORCI, 2005

observations on eleven variables, from the ORCI cancer register were cleansed in accordance with standard data cleansing guidelines similar to those outlined by Wong (2002) and Louie *et al.*, (2007) and fully anonymous. A pre-analysis coding was carried out to produce the final list of the variables as summarised in Table 1.

SOME OF THE RECENT METHODOLOGICAL APPROACHES TO CANCER

A variety of statistical methods have been used in cancer studies. Clifford *et al.*, (2003) used both logistic regression and cluster analysis in their study of human papillomavirus (HPV) in global invasive cervical cancer. Although not directly mentioned as a limitation, the use of a single model in each case was unlikely to yield reliable results especially as the authors admit that the samples were not really representative as large areas such as the Middle East and the Indian subcontinent were not included while Japan, for instance, was overrepresented.

Our study is based on a triangular approach involving applying a combination of graphical data visualisation (GDV), association rules (AR) and dimensional reduction techniques (DR) on a dataset collected from diverse locations all over the United Republic of Tanzania. The adopted approach is therefore distribution-free and may be viewed as an extension of Tibshirani *et al.*, (2002) who applied an enhanced nearest neighbour classifier to perform cancer class prediction from gene expression profiling. But while their approach was based on shrinking of the nearest neighbour prototypes for comparatively more accurate classification, we combine three approaches in search of consensual natural groupings in the data.

Our approach follows in the footsteps of Frigui and Nasraoui (2004) who proposed algorithms for learning a different set of feature weights for each detected cluster. However, rather than focusing only on generated data clusters, we combine three fundamentally different techniques in order to attain a consensual and, hopefully, more reliable labelling of the natural grouping with a potential for enhancing future predictions of cancer. In the following exposition, we provide a theoretical intuition into the mechanics of our proposed approach.

A THEORETICAL INSIGHT INTO OUR ANALYTICAL APPROACH TO THE PROBLEM

As noted above, our proposed approach is based on a combination of GDV, AR and DR techniques. Various forms of GDV methods have been developed with notable examples including Stalactite Plots (Atkinson, 1994), Mosaic Plots (Friendly, 1994) and Linked Bar Charts (Hummel, 1996). Recent applications of GDV methods in cancer research include Johann *et al.*, (2004)

and Goovaerts (2006) who applied, effectively, a combination of graphical and smoothing methods to try and improve the reliability of risk cancer estimates from sparsely populated geographical entities. For the purpose of this study we follow the method of Friendly (1994) which provides scope for comparison with the standard Bayesian approach to prediction. Hence, we describe the mechanics of both GDV and AR on the basis of the well-understood concept of conditional probabilities as follows.

The third vertex of our triangular approach is dimensional reduction (DR) two standard approaches of which are Principal Component Analysis (PCA) and data clustering (Kogan, 2007). Data clustering algorithms have been widely studied in the literature with some of the most popular algorithms including the K-Means (MacQueen, 1967) and the Kohonen Self-Organising Maps (Kohonen, 1995). Here we will only provide the general reasoning behind dimensional reduction (DR) and describe the mechanics on the basis of data clustering.

In theory, answering the question as to whether there are naturally arising structures in the data in Section 0 amounts to computing probabilities of group membership which we can illustrate as follows. We denote the vector of relevant data attributes by $V_i = 1, 2, \dots, p$ where p is total number of variables and, using our data, the data attributes vector is defined as follows:

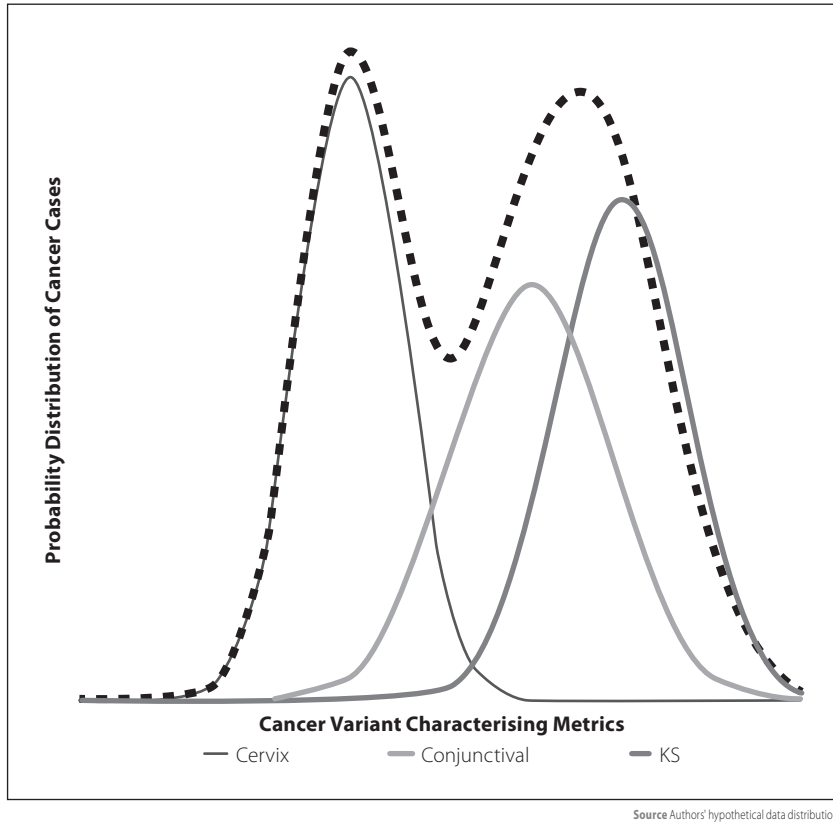
$$V_i = \begin{vmatrix} \text{Gender Age Religion Occupation Smoking Region} \\ \text{Type Topography Extent Stage HIV} \end{vmatrix}$$

Without loss of generality we can assume that each of the variables in the vector is continuous and therefore it can be discretised to form appropriate categorical interval of the form $L_j = 1, 2, \dots, J \in V_i$, where J is the maximum number of levels in that variable. Typically, a data pattern arises when we are able to describe the proportions of $L_j \in V_i$, for all variables which, for continuous variables, amounts to tracking the probability density $f(V_i)$.

From the foregoing illustrations, we can obtain three quantities of interest; the probability of data, probability of class (or level) and the conditional probability of one given the other. In a typical cancer study scenario this translates to the probability of, say, HIV; HIV and Smoking; Occupation or the probability of Type given that one is a Smoker. Computing the foregoing probabilities and conditional probabilities is equivalent to detecting distinguishable data groups in Figure 1 which, clearly, can be a rather challenging task (Silverman, 1981).

Figure 1 presents a hypothetical example based on our scenario in which our primary concern will be to clearly define the domain of each of the three types of cancer, particularly in the areas in which they overlap. The hypothetical example highlights some of the main challenges we face

Figure 1 A Typical Clustering Task May Involve Identifying Predisposing Factors Which Are Likely to Lead to One of More Types of Cancer as Graphically Illustrated Here



in data clustering; that is, resolving the overlaps and putting a label on the identified groups. Note, for instance, how the superimposed dotted line combines the two types of cancer – conjunctival cancer and Kaposi's sarcoma (KS) – and in so doing it inflates the probability of occurrence of each. The problem here is that while the unifying group minimises the ambiguity of the membership of any intersecting values between the two groups, it hides some key heterogeneous features inherent in the data. On the other hand, ignoring the dotted line reveals the data heterogeneity – yielding three groups, two of which almost unimodal – it may be a cause of spurious groups. Consequently, great care must be exercised in making final decisions on detected groups. Note that even if the three densities in Figure 1 could be computed numerically, the problem of overlap would remain.

The scenario in Figure 1 describes the underlying issues of detecting natural structures in data. Taylor and Mwitondi (2001) reported that despite the rigorous nature of most data clustering algorithms, the main challenge

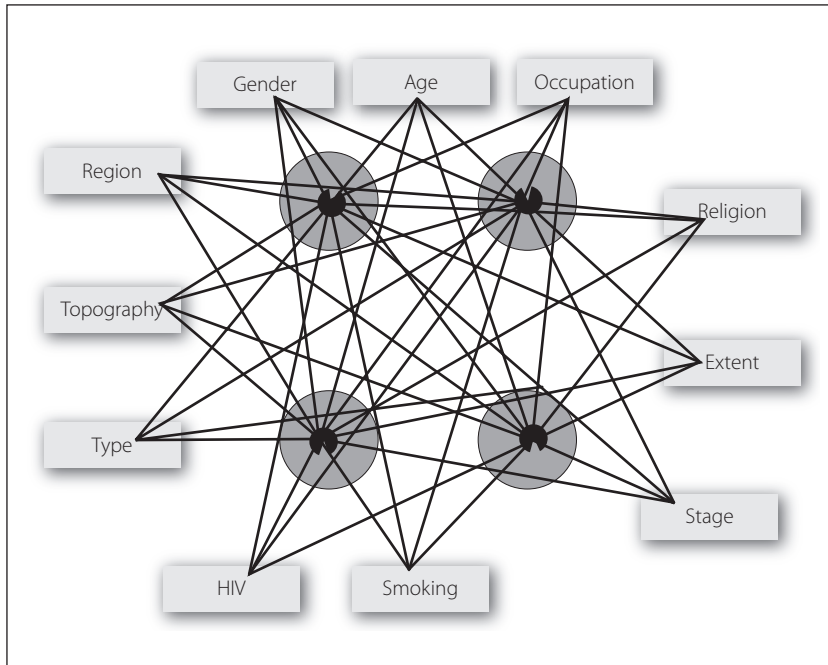
of determining “what is interesting” remains. This is mainly because, in practice, the necessary information for computing the densities are inferred from data typically using data mining or procedures for extracting knowledge from data (Mwitondi, 2003). Effectively, these are procedures and methods for “learning” rules from data; some of their theoretical foundations are outlined in Valiant (1984) and in Freund and Shapire (1997) who focused on the learning algorithms from a computing perspective whereas Hastie *et al.*, (2001) provides a statistical intuition into learning algorithms. In the next exposition, we briefly provide a theoretical account of learning rules from unlabelled data.

PROPOSED MODEL FOR HANDLING CANCER DATA CLUSTERING CHALLENGES

Learning rules from data takes, typically, two forms; unsupervised and supervised learning (Mwitondi *et al.*, 2002, Mwitondi, 2003). The former describes the scenario when the data are unlabelled and the task is to look for naturally arising groups while the latter describes the scenario when the data are labelled and the problem is to allocate each new case into one of the known groups. This paper focuses on the former as illustrated in Figure 2; a graphical illustration of our approach based on the Self-Organising Feature Map (SOFM) philosophy of Kohonen (1995). The model aims to partition the training data into groups, using information in the data attributes, in such a way elements in the same groups are as homogeneous as possible and those in different groups are as heterogeneous as possible. Our strategy will be to repeatedly apply a partitioning algorithm to map a set of finite input predisposing factors onto a 2-dimensional discrete map forming a network of a grid of the total number of inputs and a number of output defined in an $N \times M$ dimension where both N and M are greater or equal to 2 and N may equal M . The model in Figure 2 uses the simplest (2×2) topological mapping of the input space (training sample) to the output space but in most applications, including ours, both N and M will be much greater than 2. In this case, topological mapping is used both in its computing sense as simply the presentation of the logical arrangement of nodes in a network and in its mathematical sense as a process which preserves the geometrical relation of vectors.

The model in Figure 2 partitions the sample space into distinguishable regions which we could then use to describe the inherent characteristics in the ORCI cancer data. In this illustration, the sample space is represented by all four circular nodes which are formed on the basis of the information in the data attributes. The algorithms work simply by repeatedly varying the dimension of both input and output units, observing and analysing the results which will provide an insight as to whether (in this case) we

Figure 2 A 2x2 Graphical Illustration of a Topological Mapping of the ORCI Cancer Data



have detected four distinct groups or we need to increase the dimension or perhaps vary the input variables. The geometrical arrangements of output nodes will describe how close together or far apart they are, which can only be achieved if the topological structure imposed on the nodes in the network is preserved. Hence, both the computing and mathematical properties mentioned above are vital in qualifying the model as a tool of choice for clustering ORCI cancer data.

Its mechanics are based on those of the K-Means (McQueen, 1967) in that it iteratively assigns cases to centroids until convergence generating a model error at each step which reflects the difference between the empirical (or observed) and theoretical (or expected) error. So, if we denote the overall empirical error from the model by ξ_e and the notional theoretical error by ξ_t , then obviously $\xi_e \rightarrow \xi_t$, as the learning set becomes increasingly large since the former is always a random estimate of the latter. Further, if the underlying parameters are known, then the probability $P(\xi_e \geq \xi_t) = 1$ holds. However, this probability is not guaranteed to hold if both the data partitions and the underlying parameters are data-dependent as would be the case with model validation and testing. It is reasonable, therefore, to think of measuring the performance of any given algorithm by the quantity $E(\Delta) = E(\xi_e) - \xi_t$. The reliability of the model results could therefore be measured by the quantity $Var(\Delta)$.

Mwitondi (2003) has reported that the overall empirical error for most learning algorithms could be attributed to two types of randomness which he denoted by r_1 and r_2 corresponding to the randomness due to the allocation region and randomness due to the assessment of the rule with random training, validation and test data. Hence, to smooth out the randomness in drawing conclusions from learning algorithms, multiple level data clustering will be performed on the input variables combined in the manner described below.

MECHANICS OF THE PROPOSED MODEL AND THE WEIGHTING OF THE VARIABLES

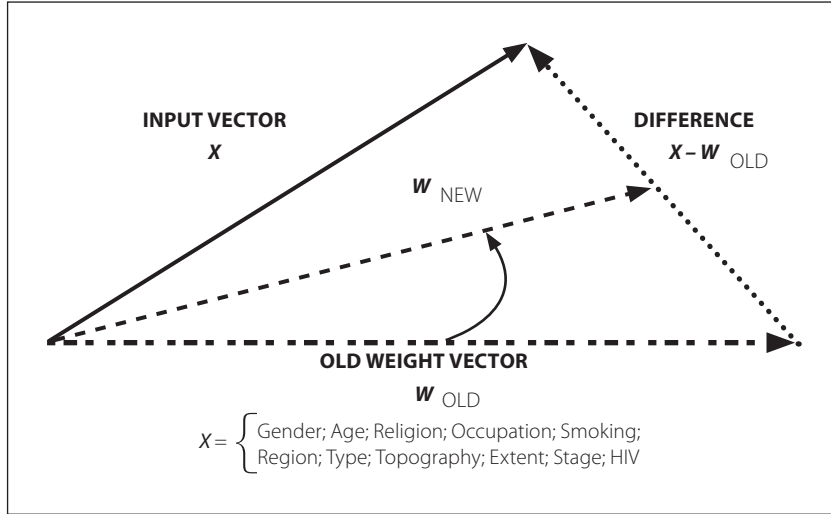
Note that the 2×2 dimensional topological mapping in Figure 2 yields potentially four clusters with each node representing a cluster and numbered from left to right such that:

- Cluster 1 corresponds to the intersection of the first row and the first column.
- Cluster 2 corresponds to the intersection of the first row and the second column.
- Cluster 3 corresponds to the intersection of the second row and the first column.
- Cluster 4 corresponds to the intersection of the second row and the second column.

Changing the dimensional topological mapping in Figure 2 as well as varying the input variables is, effectively, all that constitutes multiplicability of this study. Each time the variations are made the algorithm will work by feeding the input cancer predisposing factors onto each of the output units, with each of the input lines to each output unit carrying a weight. The weights, which symbolise the importance of each input variable, are initialised to small random numbers and are updated in the course of the learning process as follows: $w_i = w_i + \alpha(X_i - w_i)$, where $\alpha(X_i - w_i)$ denotes the change in weight and decreases to 0 as the algorithm proceeds. Alpha can be formulated as $\alpha = \eta(i, j) = 1$ when $i = j$ and decreased with the distance $|d_i - d_j|$ between i^{th} and j^{th} elements on the output vector. By learning to associate input and weight vectors without being told explicitly of the existence of clusters at the input, the network is said to undergo a process of “self-organised” or “unsupervised” learning (Kohonen, 1995). To achieve this goal, the weight vectors must be rotated around the sphere so that they line up with the training set as graphically illustrated in Figure 3.

The power of the network derives from the idea of neighbourhood, by which the network creates contour map-like patterns in the input data with the weights adjustment moving each unit in the neighbourhood closer to the

Figure 3 A Geometric Illustration of the Input Vector Weight Updating Mechanism



input pattern. Note that only the neighbourhood function varies and it is typically defined as: $\alpha = \eta(i,j) = e^{\frac{(-|d_i - d_j|)^2}{2\lambda}}$, where λ in the denominator of the exponential power is a tunable width parameter that can be altered to yield different patterns. If the parameters are well chosen, the final network should capture the natural clusters in the cancer predisposing input data. Ideally, the patterns close to one another in the 4-input space should be close to one another in the map. Neighbour nodes associated with patterns in the input data set are somehow 'close' together. Consequently, not only are patterns in the data set are detected, but also some useful information about the relationships among them may be elicited. As noted above, changing the topological map will alter the results, so to obtain optimal results, we repeatedly run the algorithms and interpret the results with the help of algorithm-independent cancer specialist knowledge as follows.

ANALYSES, RESULTS AND INTERPRETATIONS

Analysis and results interpretation in this section are presented from the perspectives of both knowledge discovery from data and oncology. Hence, the section is divided into the following main parts; an initial EDA, GDV/AR and DP of the ORCI data. We implement the methods in that order taking a stepwise look for insights into some of the key outcomes and how they highlight the necessity (or lack of it) for carrying out more rigorous investigations. All the plots in this section are based on the authors' analysis of

the ORCI collected data. The ultimate goal of the study is extract consensual patterns from the combined methods.

EXPLORATORY DATA ANALYSIS (EDA)

Exploratory data analysis (EDA) is described by Tukey (1977) as an application of a set of techniques for taking a closer look at data. One standard EDA is taking a look at the way the data attributes are distributed as illustrated by the two SAS EG (2005) generated panels in Figure 4 showing a 3-D presentation of the distribution of the three types of cancer according to age. Both panels show that, according to the ORCI data, cervix cancer is most pronounced at the age of around 50 years old and that over the age range 30 to 70 years old, cervix cancer accounts for about 71 per cent. The distribution of the variable age was examined and found to near-normal with mean 48.3729282 and standard deviation 13.6872225. Hence, the patterns in Figure 4 are quite expected for such well-behaving data. In a typical application, such normality may be masked as the 3-D plot on the right hand side panel suggests which emphasises the need to look at data attributes in their joint interaction with others.

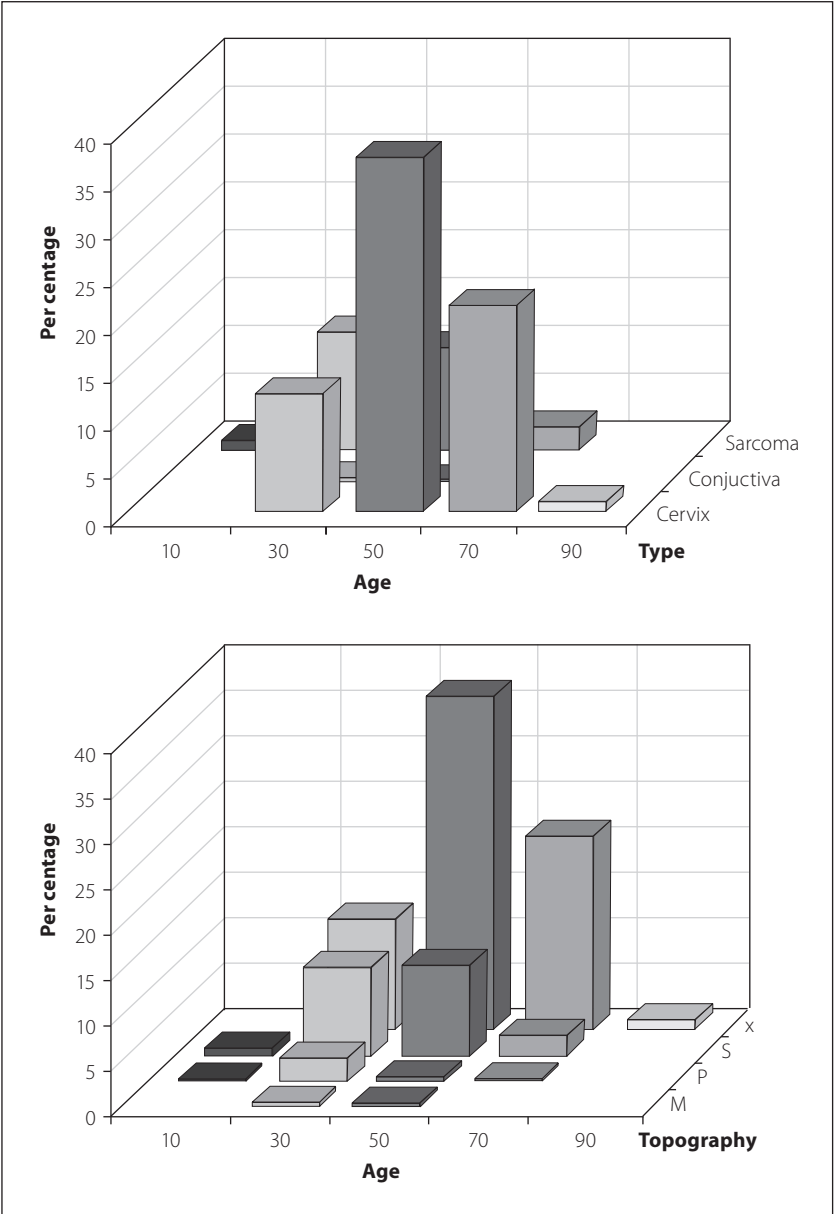
All the women in this sample had just been diagnosed with cervix cancer and considering the sample's average age, diagnosis may have come rather late. In Table 2 cervix cancer stages across the age groups are shown and as dictated by the normal behaviour of the age variable, most of the values seem to be concentrated between the age groups of 40 and 60 years old.

A distributional comparison of the three types of cancer with respect to the human immunodeficiency syndrome (HIV) is provided on the basis of Tanzania's main religious groups in Figure 5. The left and right side panels correspond to Christian and Muslim patients respectively, with the patients' HIV status categorised as "unknown, reactive and non-reactive". There seems to be consistency in patterns for reactive status between both groups but the simultaneous presence of non-reactive HIV and Kaposi's

Table 2 Cervix Cancer Stages Across Age Groups

STAGE	AGE 20	AGE 40	AGE 60	AGE 80
IIIa	0%	3%	4%	0%
IIIb	1%	13%	18%	5%
IIa	0%	6%	4%	1%
IIb	1%	13%	15%	2%

Figure 4 A 3-D Representation of an Age-Based Distribution of the Different Cancers

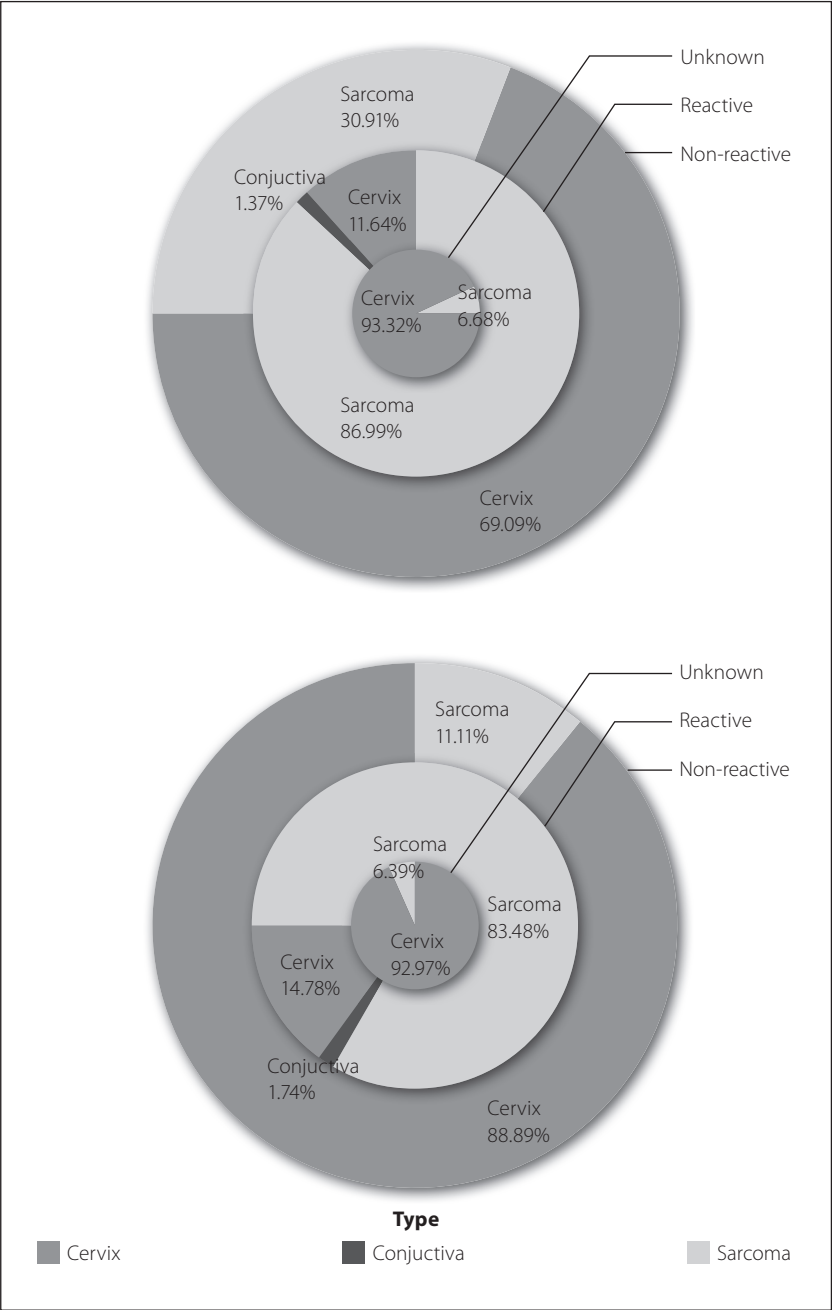


Source Generated by the authors from data

sarcoma among Christian patients is much higher than its presence among the Muslim patients.

Clearly, the EDA patterns in Figure 4, Table 2 and Figure 5 contain potentially useful information for understanding some aspects of the three types of cancer. For instance, information obtained from the two panels in Figure 5 may provide an insight into the cultural aspect of the diseases. However, the

Figure 5 A Graphical Illustration of the Relationship Between Tanzania’s Main Cultural Groups and the Three Types of Cancer (Plotted from the Data Collected from the ORCI)



patterns are, typically, data-dependent and are likely to vary across samples and so we need to smooth out the random elements (Mwitondi, 2003) and to that end we apply two more techniques; GDV and DP as follows.

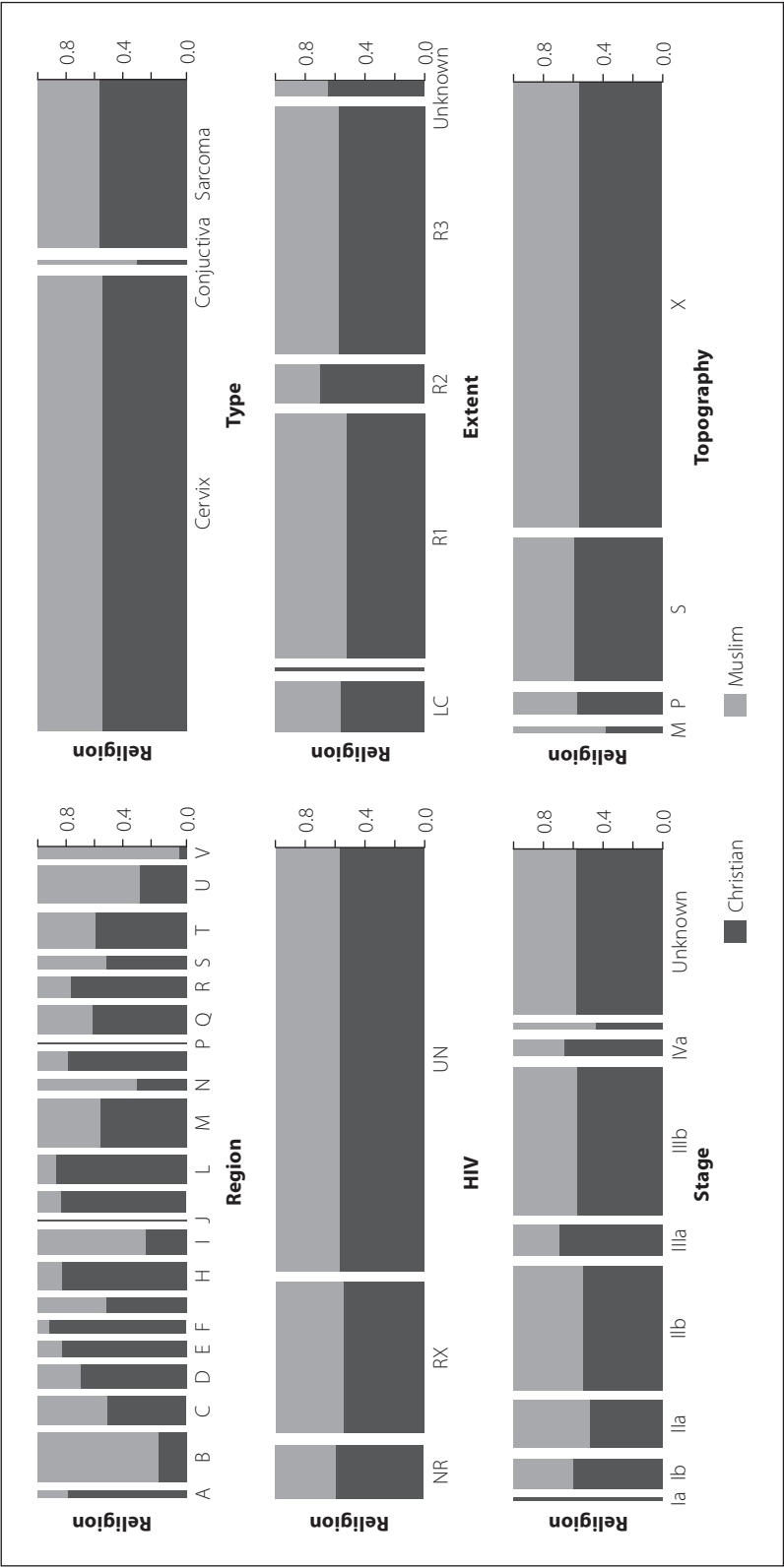
VISUALISATION OF THE ORCI DATA USING GRAPHICAL TOOLS

Graphical data visualisation was carried out using the freely available R procedures (R, 2009). The main purpose of employing this approach is to provide a comparative bridge between standard data analytics and data mining. For visualisation purposes, the Tanzanian regions: Arusha, Coast, Dodoma, Kagera, Kigoma, Lindi, Manyara, Mara, Mbeya, Morogoro, Mtwara, Mwanza, Rukwa, Ruvuma, Shinyanga, Singida, Tabora and Zanzibar were alphabetically coded as A through V respectively. The choice of variables for graphical visualisation was made in accordance with the stated research question. The plot in Figure 6 exhibits a mapping of different aspects of cancer on the country's main religious faiths. In each of the six panels, the vertical direction on the right hand side represents a cumulative probability of the variable on the horizontal axis conditioned on the left hand side vertical direction (Religion). Clock-wise from the top left, the first panel shows that other than in the Coast, Lindi, Mtwara, Tanga and Zanzibar regions, the vast majority of cancer patients were predominantly from the Christian faith. Overall, the second panel shows that over 60 per cent of cervix and KS cases occurred among Christians while about 70 per cent of

Map 1 Visualisation of the ORCI Data Using Graphical Tools



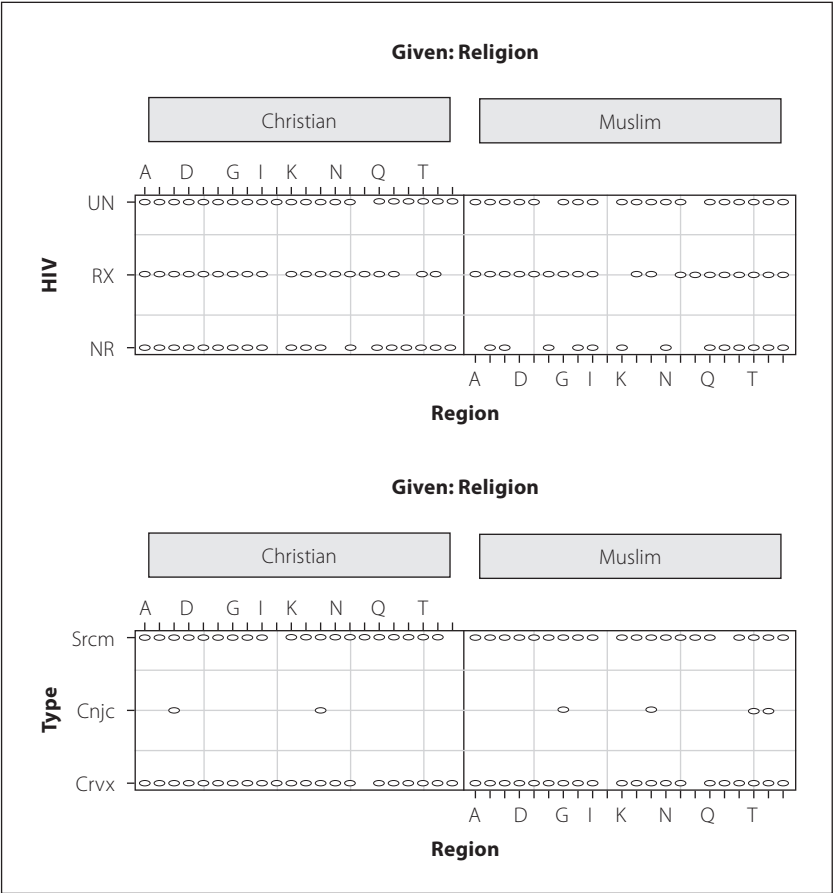
Figure 6 Mapping of Various Aspects of Cancer on the Country's Main Religions



conjunctiva cases occurred among Muslims. The third and fourth panels for cancer extent and topography both exhibit a much higher proportion of Christians in all categories; except for category M of the topography in which Muslims feature by over 60 per cent. In the fifth panel, other than for stage IIa and IVb, Christians are recorded at higher proportions in all stages. The same pattern is evident in the sixth panel (HIV) which is theoretically defined by the three cancers.

Further interpretation of the foregoing graphical images can be carried out in conjunction with the two pie charts in Figure 5 in which the exceptionally high proportion of KS among the Christian patients is in full agreement with the sixth panel in Figure 6. Based on the original ideas in Cleveland (1993), Figure 7 provides another method for visualising data via conditioning variable relationships of interest (in this case between the geographical region and types of cancer on the one hand and HIV on the other) on another variable (Religion, in this case). Higher incidences are depicted by the concentration of dots and it can clearly be seen that the results here are in full agreement as those in Figure 5 and Figure 6.

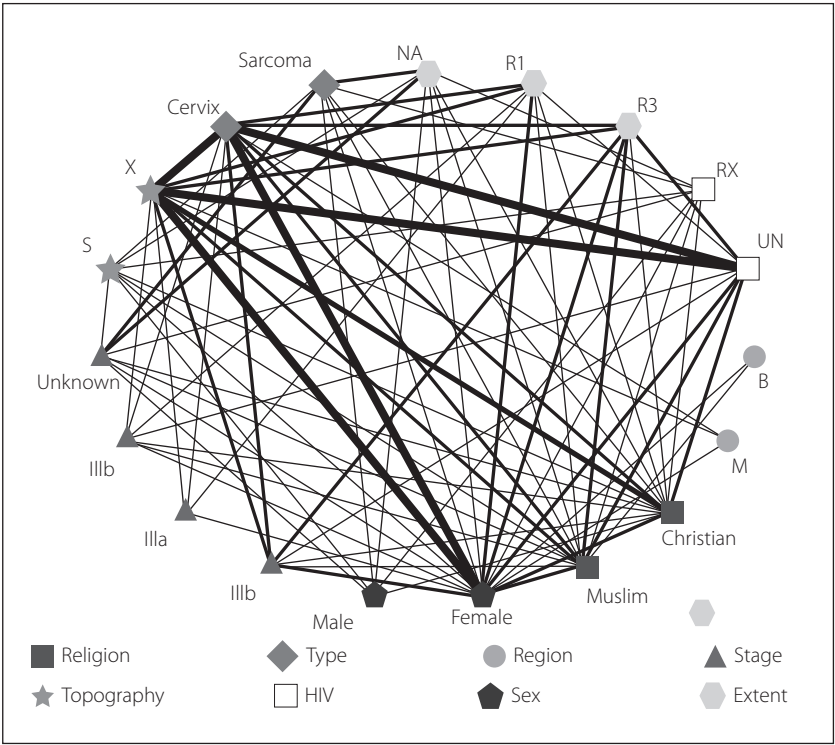
Figure 7 Conditioning of HIV/Region and Type/Region on Religion



ASSOCIATION RULES

In this section we apply association functions to the data in Table 1 in order to detect underlying rules among the data attributes. The rules should provide an insight as to whether or not, $L_j \in V_i$ and $L_{k \neq j} \in V_i$, for instance, occur together which amounts to evaluating the conditional probability $PL_j \in (V_i \mid L_{k \neq j} \in V_i)$. Without delving further into the mechanics of this approach, suffice it to say that in theory, we need to look to the magnitude of this probability and the closer it is to 1 the higher the likelihood that the two factors occur together. The results, presented in Figure 8, with stronger relations indicated by thicker lines, provide a graphical summary of the foregoing conditional probability $\forall_{L_j}$ and $\forall_{L_{k \neq j}}$. Despite not providing numerical probability values, the patterns between the different levels of the data attributes can clearly be seen. For instance, one obvious association is the one between cervix cancer and Sex (Female) but, probably more interestingly, is that despite the relatively strong association between being a female and being a Muslim, the Muslim-cervix association is much weaker than the Christian-cervix one. Similarly, marginally higher associations exist between females of the Christian faith and non-reactive HIV (UN) than among their Muslim counterparts which also applies to the males' associations with Kaposi's sarcoma.

Figure 8 Graphical Associations of the Data Attributes in Table 1



The rules in Figure 8 are extracted under the assumption that the co-occurrence of, say, religion and cancer type does have a direct impact on how, say, the geographical location influences that type of cancer. Reducing the number of variables will usually show stronger associations and to avoid that stereotype, we used all the variables, except Smoking and Occupation. A typical association rule set will contain too many associations and it is upon the investigators to streamline them. In this application, we experimented with many different settings before settling on the patterns in Figure 8 after considering the key underlying parameters such as the rule support, confidence and lift. For instance, all the visibly light lines had a lift value close to 1; indicating that and appeared almost as often together as expected or that the factor upon which the probability is conditioned had almost no impact on the occurrence of the other factor.

PARTITIONING OF THE ORCI DATA

All data clustering in this section was carried out using a combination of SAS EM (2003) and Clementine (2005)-embedded clustering algorithms. Using all data attributes we initialised a partitioning algorithm in the latter to generate five initial clusters as shown in Table 3. The clusters are shown with their corresponding number of cases with each cluster characterised by a quantity depending on the variable type. In each cluster, a numeric variable such as Age is represented by the average age of patients in each particular cluster while the proportions for each distinct value will be given for each of the string variables such as Religion, Smoking or Extent. For instance, Cluster 2 in Table 3 is exclusively male suffering from Kaposi's sarcoma and just over 62 per cent of whom happen to be Christians.

Convergence into the five cluster locations in Table 3 was reached after five iterations with sequential errors 1.18, 0.45, 0.28, 0.23 and 0.00. With Cluster 3 in Table 3 containing only six cases, it was reasonable to try and reduce the number of clusters to three which yielded the results in Table 4, obtained after six iterations, with errors 1.405, 0.504, 0.273, 0.042, 0.044 and 0.00. Interpreting the clusters is central to any data clustering exercise. How do the three-cluster results compare with those from the initial five-cluster scenario? Here Cluster 1 is exclusively female with 56.53 per cent being of the Christian faith and (as expected) almost all suffering from cervix cancer. The cluster, which now has over 73 per cent more cases, contains about the same information as does Cluster 1 in the five-cluster setting. It is evident from the two settings that the religious attribute (Muslim) does not play any central role in forming clusters; other than the exceptional case of Cluster 3 in the five-cluster setting which is predominantly conjunctiva.

Table 3 Allocation of the ORCI Data in a Five-Cluster Scenario

Cluster	Total Cases	Age	Gender	Religion	Occupation	Smoking	Type	Topography	Extent	Stage	HIV
1	456	50.638	100% Female	55.92% Christian	88.82% Housebound	99.12% Never	100% Cervix	100% X	71.49% region1	52.19% I1b	85.09% Unknown
2	179	41.419	100% Male	62.01% Christian	48.6% Housebound	85.47% Never	100% KS	89.94% S	99.44% NA	100% Unknown	69.83% Reactive
3	6	36.333	66.67% Female	66.67% Muslim	83.33% Housebound	83.33% Never	100% Conjunctiva	100% M	100% Localised	100% Unknown	66.67% Reactive
4	114	37.439	100% Female	53.51% Christian	80.7% Housebound	98.25% Never	100% KS	80.7% S	99.12% NA	100% Unknown	86.84% Reactive
5	331	52.997	100% Female	57.7% Christian	93.35% Housebound	99.4% Never	100% Cervix	100% X	100% region3	86.1% I11b	89.12% Unknown

Source ???

Table 4 Allocation of the ORCI Data in a Three-Cluster Scenario

Cluster	Total Cases	Age	Gender	Religion	Occupation	Smoking	Type	Topography	Extent	Stage	HIV
1	789	51.588	100% Female	56.53% Christian	90.75% Housebound	99.24% Never	99.75% Cervix	99.75% X	41.95% region3	36.12% IIb	86.82% Unknown
2	253	40.696	63.64% Male	58.89% Christian	61.26% Housebound	89.72% Never	100% KS	100% S	99.21% NA	100% Unknown	73.91% Reactive
3	44	34.864	34.864% Female	56.82% Christian	61.36% Housebound	93.18% Never	90.91% KS	86.36% P	90.91% NA	100% Unknown	93.18% Reactive

Source ???

DISCUSSIONS, CONCLUDING REMARKS AND POTENTIAL DIRECTIONS

As in Kamangar *et al.*, (2006), this study found sufficient evidence of the potential cultural influence on cancer patterns. The main results from all three methods revealed a strong influence of the religious influence on the types of cancer and, implicitly, HIV. Although confined to a closed region, the analyses are expected to stimulate or contribute to related studies across the continent and contribute to knowledge sources on the homogeneity or heterogeneity of the various types of cancer across the world. We demonstrated that by combining the power of GDV, AR and the DP, we can obtain, from the sub-domains, a comparative basis for assessing and evaluating the interaction of the predisposing factors which may provide some useful insights into informed intervention, prevention and treatment of the diseases. We showed how the proposed triangular approach was capable of uncovering subtle relationships among data attributes which presents a rigorous basis for assessing and evaluating the impact of predisposing factors on the three types of cancer.

The power of the methods notwithstanding, we still need to address a number of underlying issues. More specifically, it is hard to envision a universal optimal model for, say, detecting patterns for various cancer types in different geographical areas over a varying period of time. To achieve that precision, approaches to cancer data analysis require an efficient combination of data, analytical tools, techniques and interpretations which are readily responsive to the inherent dynamics. For instance, in searching for an optimal number of natural groupings in the data, it was imperative to retain the five-cluster setting rather than the three-cluster setting so as to avoid masking the seemingly important relationship between a cultural aspect (Muslim) and conjunctiva cancer. Further, the variable Region was not considered useful in forming the clusters in Table 3, but this may be because it had too many levels to make an impact. As highlighted in Figure 1, the key issue in running clustering algorithms is deciding on what is interesting. Thus, if the variable region failed to distinguish clusters it may well have been due to the homogeneous nature of most Tanzanian regions. For instance, the regions with high proportions of Muslims, in which conjunctiva was more pronounced, are not only located in the same geographical vicinity, but also have many similar cultural attributes. Thus, in further studies, it may be useful to divide the country into a finite number of zones; reducing the variable numbers to, say, five levels: North, South, Central, East and West.

For instance, the simple patterns in Figure 4 and in Table 2 may highlight the plight most women on the African continent face in relation to the cervix cancer. In a comprehensive study of cervical cancer in the United States, Saslow *et al.*, (2002) reported that about 50 per cent of all the cases diagnosed

in the country occurred among women who had never been screened. One of their recommendations was that cervical cancer screening start approximately three years after the onset of active sexual life among women. A study by Sasiani *et al.*, (2003) carried out in England where the screening age range was between 25 and 64 years old recommended allocating more resources to screening young women in the low risk age group of 25 and 40. Comparing these statistics to the cervix cancer average age in Table 3, Table 4 and Figure 4 reveals a huge functional contrast between the western cancer studies and Tanzanian. Further, the fact that there was no prior information as to when these women developed the first signs of cancer, suggests that launching earlier awareness campaigns, preferably through religious groups (in consideration of the impact of the variable Religion) may be instrumental in running effective intervention programmes.

One way of reaping the benefits is to collate results from various analyses for use as inputs in formulating and designing a prototype model for updatable cancer-related data sources and storages aimed at connecting cancer registries across the African continent and beyond. Setting up cancer registers at various cancer-research centres across the continent is a step forward towards achieving those goals. By archiving and making use of findings from various studies the cancer research community will be able not only to assess and evaluate the current models used in predicting various types of cancer but will also make it possible to enhance them and develop new ones. It is essential that the insights gained from the study objective are used in enhancing the predictive power of the models used in estimating risks of people developing cancer. If we can keep track of the characteristics of people who develop the disease and those of who recover from it we will have provided a basis for controlling and managing the disease for which African cancer registers will have to be open to one another.

Finally, despite the findings being confined to Tanzania, it is reasonable to assume that, given the country's diversity, results from this study will provide some useful guidelines into informed intervention, prevention and treatment of the diseases beyond its borders. Hence, we expect that the study will contribute to the geo-ethnic cancer knowledge base as well as highlighting the modalities of a cross-border multi-disciplinary working platform in cancer research. The results can be also be used as inputs in formulating and designing a prototype model for updatable cancer-related data sources and storages aimed at connecting cancer registries across the African continent and beyond; hence helping to provide potential shifts in concepts, definitions and the baseline behavioural understanding of various types of cancer. By adopting a variety of analytical methods in analysing the interaction of cancer data attributes, applying the consensus-searching triangular model and interpreting the results in a multi-disciplinary context, this paper sought to

achieve that goal. It, therefore, can be viewed as having presented an unprecedented approach to addressing cancer-related research issues.

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Remote Sensing and Geological Investigation of Okemesi Area, Southwestern Nigeria

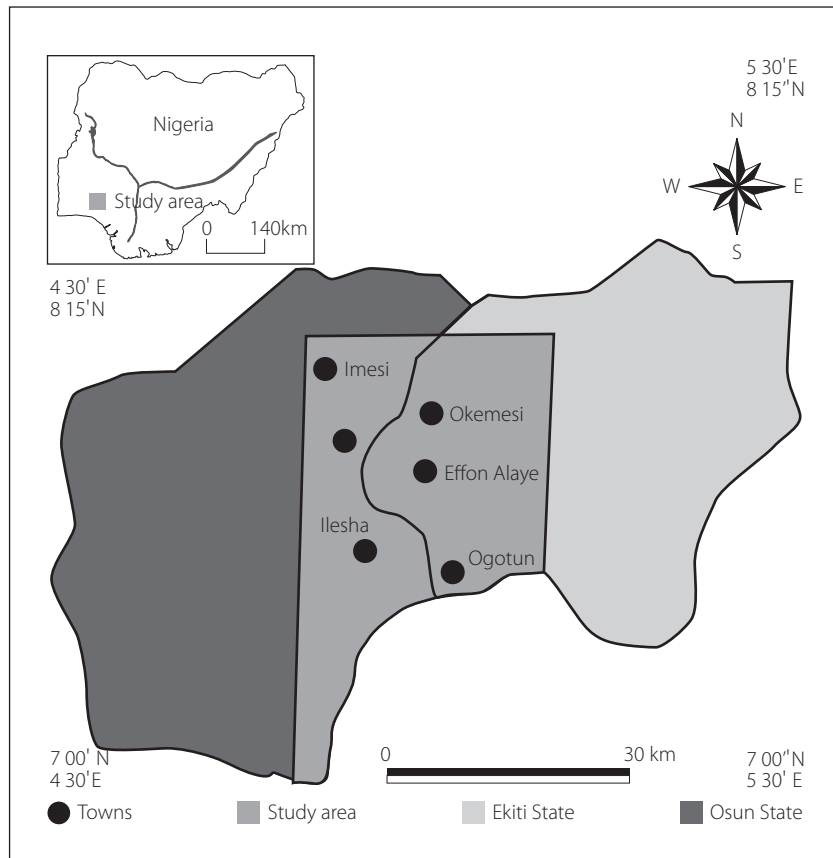
Olusiji Samuel Ayodele

INTRODUCTION

Remote sensing is a versatile tool in geology which has wider applications. It has been used successfully in mapping rocks and structures. Sometimes, these structures are difficult to observe on the field during geologic mapping due to the rugged nature of the terrain. Often, the terrain is made up of thick, tropical forests that are difficult to access for the field geologist, most especially in the southern part of Nigeria. However, with the advent of remote sensing and the new developments in spatial, spectral and radiometric resolutions and their wide range of view over a short period of time, the application of remote sensing in geologic mapping has greatly helped in making the entire structural setting of a whole belt become clearer, thus rendering hitherto lengthy, tedious and expensive mapping unnecessary (Rahaman, 1976, Odeyemi, 1993). Individual remote sensing systems are limited by costs, weather dependency and cloud cover penetrability. Some of these problems have been reduced with the advent of sophisticated remote sensing systems such as SPOT and LANDSAT THEMATIC MAPPER (Landsa™) with their more efficient characteristics. Structures can be picked by active radar systems. Side Looking Airborne Radar (SLAR) has an all weather capability and illuminates the terrain with its own microwave energy (Larson, 1968, Gellnet and Gardner, 1979). Other megascopic geologic features such as folds and faults and other lineaments are picked up by the satellite systems such as the one acquired for this study based on their ground resolutions. However, remote sensing also provides fast means of covering large areas at low economic costs and the geological maps produced from remote sensing brings into focus many structural details that might be overlooked on the field.

Geographically, the study area is situated between latitudes 7° 39'N and 7° 59'N and longitudes 4° 39'E and 4° 59'E. It covers an estimated area of 1369km² , and can be located in the half degree topographical map sheet No

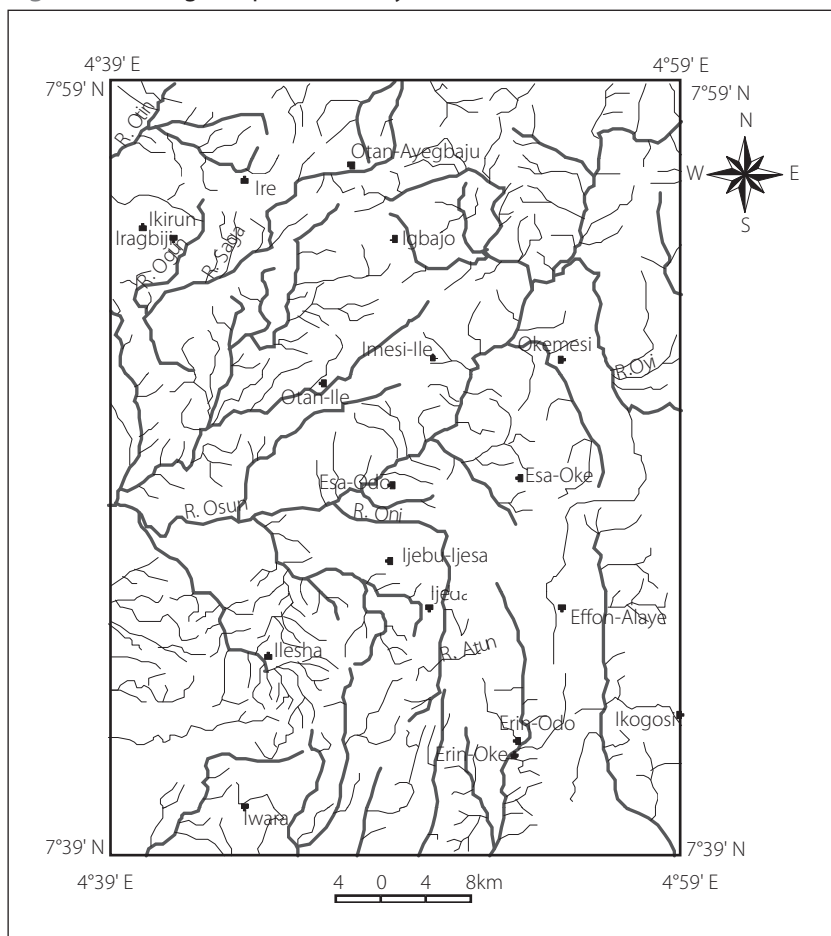
Figure 1 Map of Osun and Ekiti States Showing the Study Area (Inset Map of Nigeria Showing Both Osun and Ekiti States)



243 (Ilesha sheet 1:100,000). Some major towns in the area include Okemesi, Efon Alaaye and ogotun which are shown on the location map (Figure 1). Except for the highly rugged terrain in and around Imesi Ile, the area is generally accessible through a good network of all seasonal roads and motorable tracks which link it with other parts of the country. The drainage pattern in the southeastern part of the area where the topography is dominated by series of ridges is the trellis type (see Figure 2). This suggests that the drainage here is structurally controlled. In the other parts of the study area, the drainage pattern is dendritic due to homogeneity of the rocks.

REGIONAL GEOLOGIC SETTING

The study area lies within the Precambrian Basement Complex of south-western Nigeria, which itself is a part of the Basement Complex of Nigeria. The study area is underlain by crystalline rocks ranging from Precambrian

Figure 2 Drainage Map of the Study Area

to Paleozoic. These rocks have been grouped into six lithologic units by Rahaman (1988) as follows:

- Migmatite-Gneiss-Quartzite Complex
- The Schist Belts
- Charnockites
- Older granites (Granitoids)
- Volcanics, Gabbroic and Dioritic rocks
- Unmetamorphosed dolerite and syenite dykes

LOCAL GEOLOGY OF THE STUDY AREA

The study area is dominated by quartzites, granites, schists and migmatites with well defined boundaries. The boundary between the schists and

quartzites on the imagery is separated by a NNE-SSW trending fault known as the Ifewara fault. This fault is curvilinear and runs nearly parallel to the strike of the quartzite ridge on the imagery. It also divides the Ilesha schist belt into two groups of contrasting lithologies, a group of amphibolites, amphibolite schists and pelitic schists on one hand, and another group comprising quartzites, quartz schists and quartz-feldspathic gneisses. A school of thought believes that Ifewara fault is a transcurrent fault (Odeyemi, 1992), while others believe that it has a thrust relationship (Boesse and Ocan, 1988). Hubbard (1975) and Odeyemi (1993) suggested an overthrust relationship between the amphibolites and the rocks of the Effon Psammite Formation with associated quartz-feldspathic gneisses, while Turner (1983) suggested that the fault might represent a collision suture. The foliation trend in some parts of the study area is flat as revealed by the dipping angles of the rocks around Effon and Ijeda. Around these areas, the dips are as low as 30° which suggests thrust movements and likelihood of nappes in the areas. This is in contrast to other areas where the dips as high as 80° have been recorded, suggesting a nearly vertical foliation. The Effon Psammite Formation is folded into an antiform with a prominent north plunging closure at Okemesi. The quartzite ridge also overlies the strongly deformed Ilesha metaclastics and commonly displays linear structural styles.

Some work has been done in terms of geologic and structural mapping of the area. Anifowose *et al.* (2007) noted that joints ranging from minor to major ones are found in all rock types, some of which are filled with quartz, feldspar or a combination of both. They lie generally in the NE-SW directions. Odeyemi *et al.* (1999) suggested that almost all foliations exhibited by rocks of south western Nigeria excluding the intrusives are tectonic in origin, because pre-existing primary structures have been obliterated by subsequent deformations. The general north-south trend of major fractures and foliations within the basement complex is as a result of deformation. However, a few workers have carried out analysis of remote sensing data of parts of the area. Ayodele (2006) carried out a remote sensing evaluation and geological studies of the area. The scope of the work entailed interpreting a LANDSATTM image covering the entire area, followed by minimum ground truth. A total of 260 lineaments were extracted from the different rock units that underlie the study area. Also, folds and fractures were detected on the imagery which are evidences of different episodes of tectonic deformation. On the other hand, the fractures seen on the imagery probably represented joints and faults. The ground truth confirmed the presence of overturned antiformal and asymmetric folds, while the faults seen on ground were attributed to fractures that occurred during the folding episodes in the area. Anifowose (2003) carried out an integrated remote sensing analysis of the Ifewara-Zungeru Megalineal

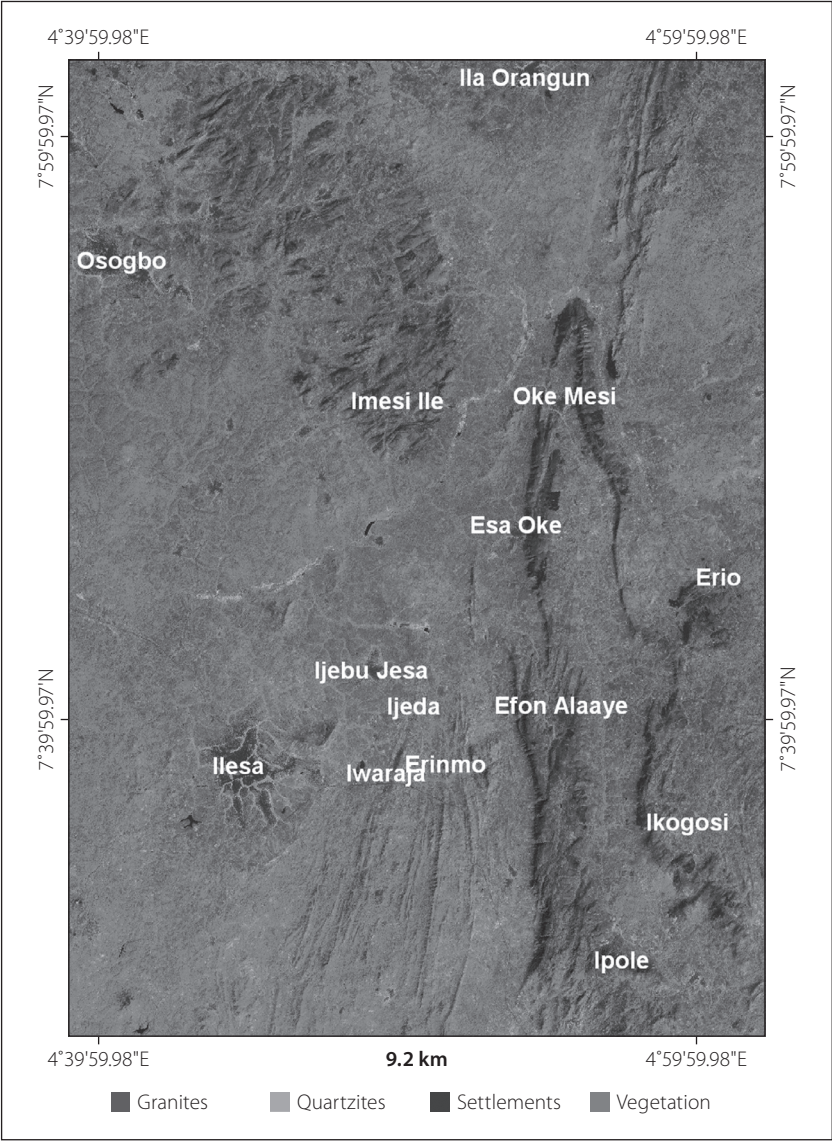
using remotely sensed imageries (AERIAL PHOTOS, LANDSAT and SLAR). The results showed that there are two general sets of fractures namely; the NNE-SSW set and E-W set which is normal to the orientation of the quartzite bands associated with gold mineralization in Ilesha area, and suggested that the continuity of Ifewara-Zungeru fracture system indicates a possible alignment with an oceanic fracture zone through the submarine Okitipupa Ridge. Odeyemi (1993) also did a comparative study of some remotely sensed images on the structure of the Okemesi Fold Belt, southwestern Nigeria. From his research it has been deduced that SLAR is very useful for structural studies of a region, in terms of lineaments detection because of its double (i.e. north and south) look directions. Odeyemi (1992) also carried out remote sensing analysis of the region around Ifewara fault using remotely sensed images, and concluded that combinations of transcurrent and dip slip movements may have taken place along the fault at various times. Boesse *et al.* (1989), Caby and Boesse (2001) have inferred and described the presence of nappes from the shallow dips of foliation and shear zones, low angle thrusts and associated recumbent folds in the Ife/Ilesha area.

This study is aimed at demonstrating the usefulness of remote sensing in geologic mapping of the Precambrian rocks around Okemesi area; and to confirm whether the digitally interpreted landsat imagery conforms with field observations by ground truth.

METHOD OF STUDY

For the purpose of this work, a LANDSATTM imagery of band 4-3-2 was acquired from the Regional Center for Training in Aerospace Surveys (RECTAS), Obafemi Awolowo Campus, Ile-Ife. The imagery was extracted for digital processing (see Figure 3). This imagery with which the coverage of scene is of 185km by 185km was published in the year 1991 and has a spatial resolution of 30m. The imagery was georeferenced using twelve selected Ground Control Points (GCPs) from the topographical map of the study area. This imagery has some unique characteristics like an extended spectral range in the visible and reflected infra red regions, the addition of blue spectral band (Thematic band) that enables production of natural colour composite images and a Thematic mapper (TM) which has a Thermal Infrared (TIR) band and improved radiometric resolution. The imagery was digitally processed. The procedure employed for the digital processing of the imagery included image enhancement which involved assigning a digital number (DN) value from 0-255. (0 value was assigned to extreme black while 255 was assigned to white) The remaining pixel values were distributed linearly between these extremes. This helps to enhance individual

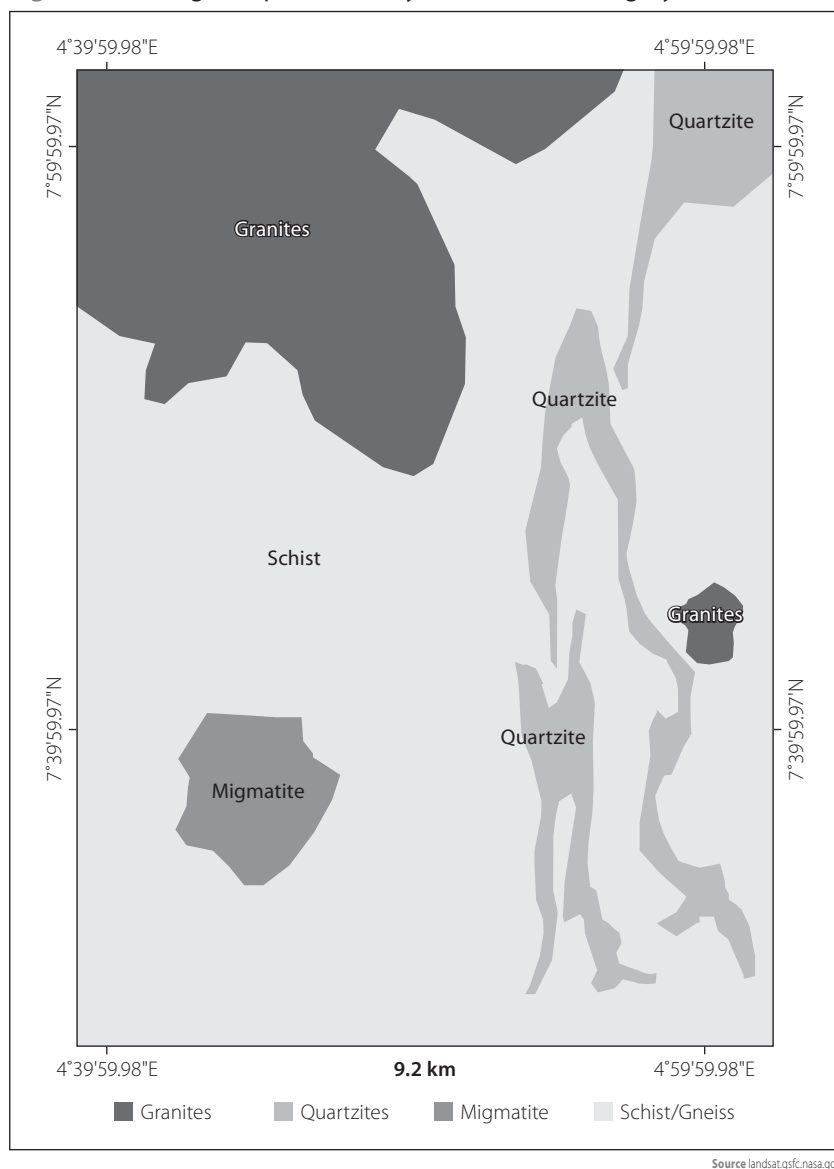
Figure 3 A LANDSAT™ Band 4-3-2 Image of the Study Area



Source landsat.gsfc.nasa.gov

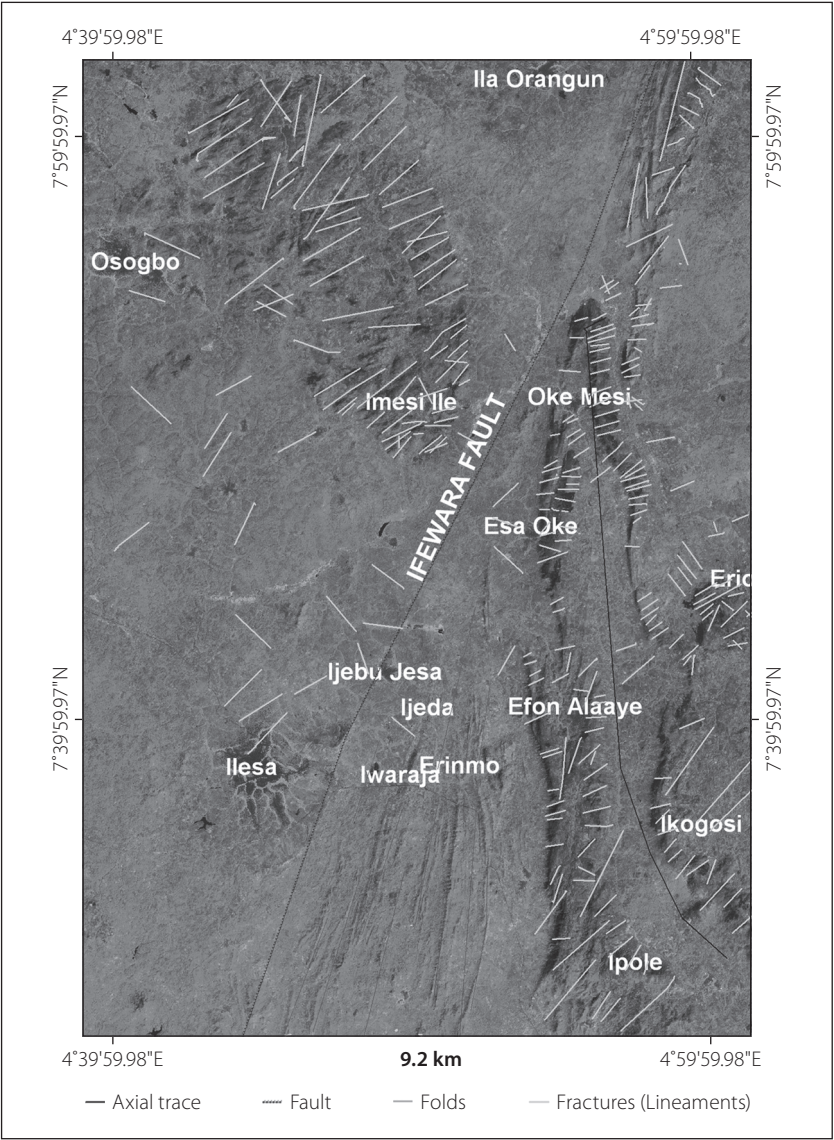
rock units. This was followed by filtering to sharpen the satellite image and to detect line features such as fractures, geological boundaries, rivers and drainages. Average (AVG) filtering method with low power filtering was used to improve the resolution of the final image. This method (AVG) calculates the average value of 9-pixel values considered (3x3 matrix). This helps to delineate major lineaments and gives a high contrast level between adjacent terrain objects.

Various band combinations were attempted but bands TM 4-3-2 was eventually used because it gave the best results, because it enhances the

Figure 4 Lithologic Map of the Study Area from the Imagery

geology and structure of the study area. From this combination, the spectral qualities obtained enabled the determination of spectrally homogeneous areas or zones within the image. It was then possible to extract structural information from the image by producing a lineament density map of the area (see Figure 5). The results obtained from the image processing were also used to produce the lithological map of the study area. This was done by delineating the boundaries of the recognised lithologies on the image (see Figure 4) (quartzites, granites schists/gneiss and the basement migmatite) by assigning distinctive colour to represent each of the lithologies.

Figure 5 Lineament Density Map of the Study Area

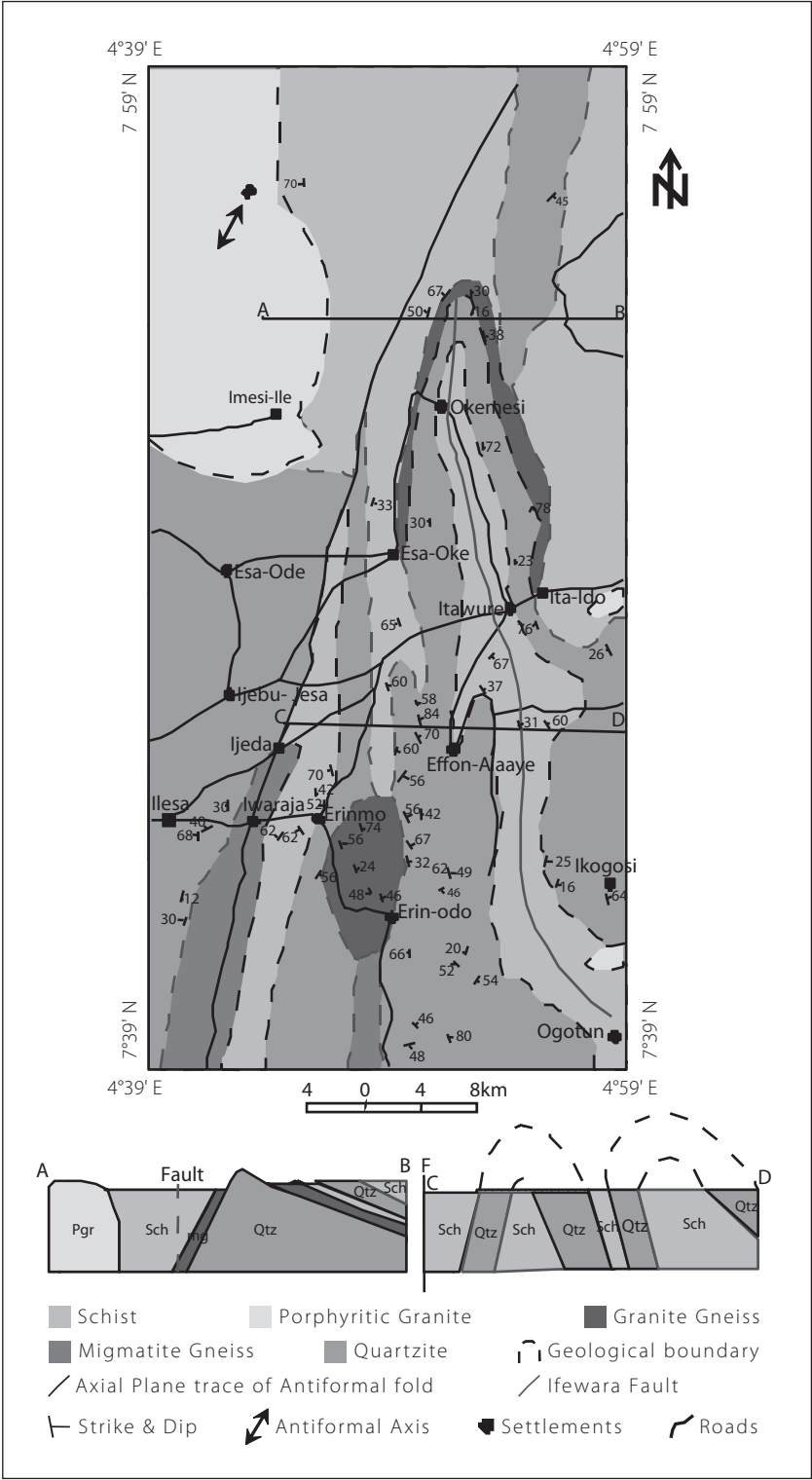


Source landsat.gsfc.nasa.gov

RESULTS AND DISCUSSION

Four distinct lithologies were extracted from the interpreted imagery on the basis of their spectral reflectance (see Figure 4). These lithologies are the granites, which occupy the northwestern part of the imagery, the quartzites located on the eastern part, as well as in the SSW part of the imagery, the schists which is the most dominant rock in the study area, and migmatites which occur as peneplains within the schist areas. Structures including folds and faults were interpreted from the imagery containing the lineament

Figure 6 Geological Map of the Study Area

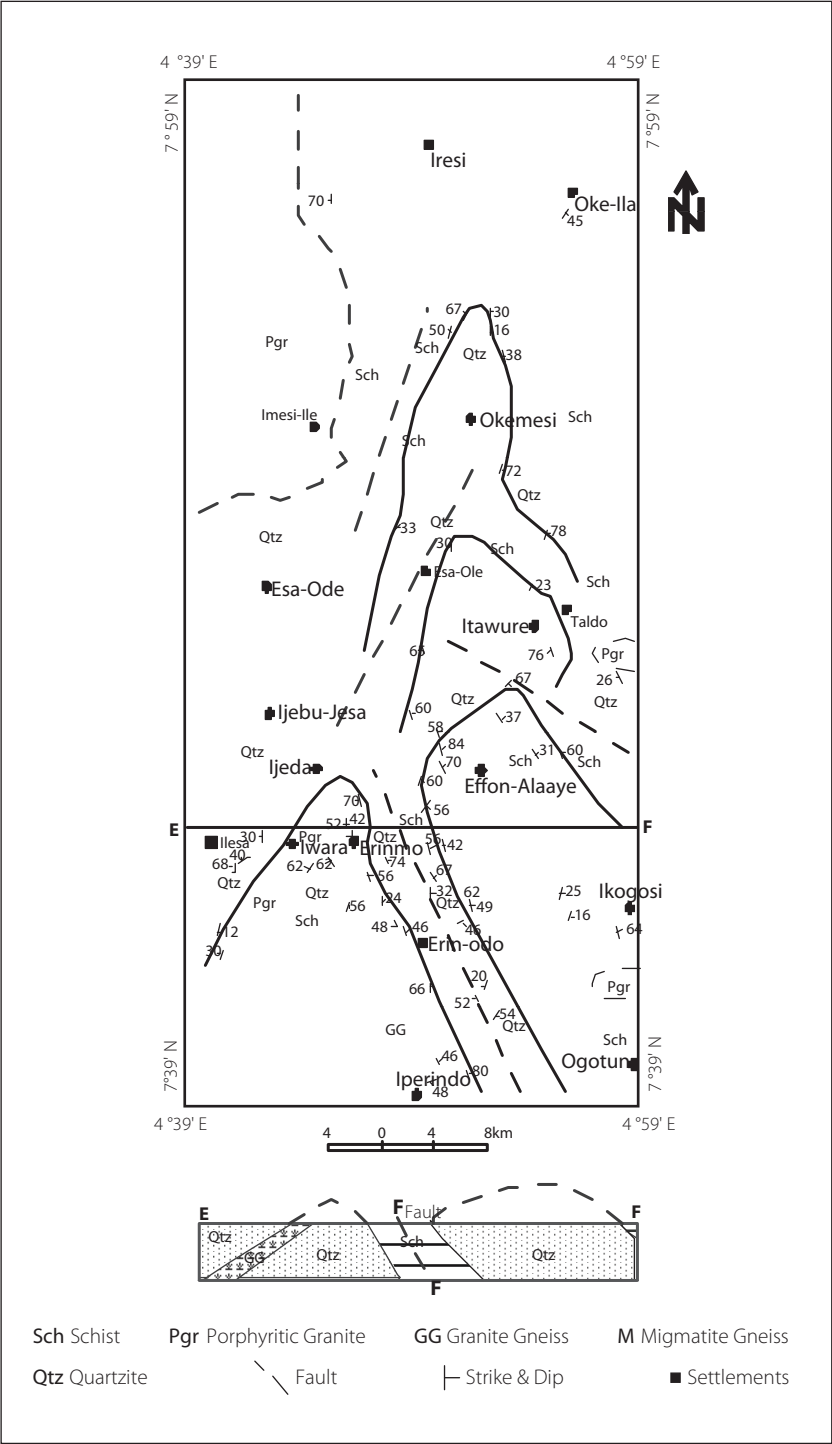


density map (see Figure 5). The folds trend linearly in a NNE-SSW direction on the imagery, they are multiple and bear imprints of different episodes of tectonic deformation. However, the prominent folded structure on the imagery is the Okemesi antiform. Two categories of fractures were also interpreted from the image; the major fracture which is the Ifewara fault is a curvilinear fault that is nearly parallel to the strike of the quartzites, while the minor fractures were noticed on the quartzite limbs.

On the geological map (see Figure 6) five distinct rock units were mapped. These are the schistose quartzites (referred to as the Effon Psammite Formation), schists, migmatites, granite gneisses and granites. The gneisses are interbanded with quartzites, the migmatite forms the basal rock while the schistose quartzite is the youngest rock. The granite gneiss forms discrete linear bodies from Iperindo to Ijeda and as dismembered bodies around Orimolade hill at Effon while the Pan African granites occur in the northwestern part of the study area as Imesi-Ile granitic pluton. Foliations on the quartzites trend roughly N-S at Erinmo. The cross-section obtained from the geological map (see Figure 6) showed that the folds mapped in the study area are overturned antiformal fold while the cross-section from the structural map (see Figure 7) indicated that the folds are asymmetric folds. One limb of the asymmetrical fold dips steeply eastwards, while the other limb dips at low angle in the opposite direction. It was also observed on cross-sections drawn from the geological map (see Figure 6) that the schistose rocks are the faulted rocks in the study area which are seriously affected by the impact of Ifewara fault, the quartzites are folded and fractured while the granites are also fractured. The density of fractures on the quartzites are higher, followed by the granites and lowest on the schists and migmatites (see Figure 5). This could be attributed to the transgressive deformation that occurred during folding episodes in the area. Other fold types such as tight folds, isoclinal folds and especially recumbent folds, identified on the basis of the position of their axial plane, and are common in Ajindo area of Okemesi could only be detected by field observations and measurements during the ground-truth exercise. Some of these folds are separated by assumed fault zones (see Figure 7).

A comparison of the lithologic map (see Figure 4) obtained from the interpreted imagery (see Figure 3) and the geological map (see Figure 6) obtained from ground truth revealed that four lithologies were identified from the former and five from the latter. On the lithologic map (see Figure 4), the schists and gneisses do not have any lithologic boundaries because they have the same spectral reflectance. However on the ground, they were resolved as each of them have distinct lithologic boundaries. This shows that field mapping is more effective in lithological studies of an area than remote sensing. Whereas, in terms of structural mapping of an area on a

Figure 7 Structural Map of the Study Area. (Produced by matching areas dipping in the same direction to generate folded structures as part of field checks)



regional scale, remote sensing is a vital tool in the mapping of mega structures like lineaments, faults and folds which can not be seen easily on the field. Walker (2006) did a similar work, by carrying out a remote sensing study of active folding and faulting in Southern Kerman Province S.E Iran. The result revealed a major oblique fold and thrust belt which appear to link the Sabzevaran right lateral strike slip faults in south east Iran to other strike slip faults within the interior of the country.

The schists and schistose quartzites were observed in the field to have been seriously affected by chemical weathering in the study area, forming soils on which thick vegetation has grown. In some places the rocks have weathered into large bodies of residual feldspathic clays. The weathered rocks may also form lateritic caps on the underlying sequence in other places such as Itawure and Ido-Ile. Unlike the schists and the schistose quartzites, the migmatites, gneisses and the granites have suffered very little chemical weathering. Consequently, the areas they underlay have thin or no soil cover and are sparsely vegetated. Vegetation is, however, prominent in the joints and cracks which are developed on the rocks due to mechanical weathering. The overall picture of the study area from image interpretation and field studies confirmed that folding actually took place, and the various structures detected on the imagery and mapped on ground are products of geotectonic deformation. The rocks in the study area are seriously affected by this deformation and their responses to these deformation vary from one rock to the other based on their mechanical strengths. For example, boundinage structures were seen on the migmatite-gneiss outcrop at Erinmo. This could be attributed to development of schistosity in the more ductile beds accompanied by plastic deformation of the more rigid strata on the folded flanks.

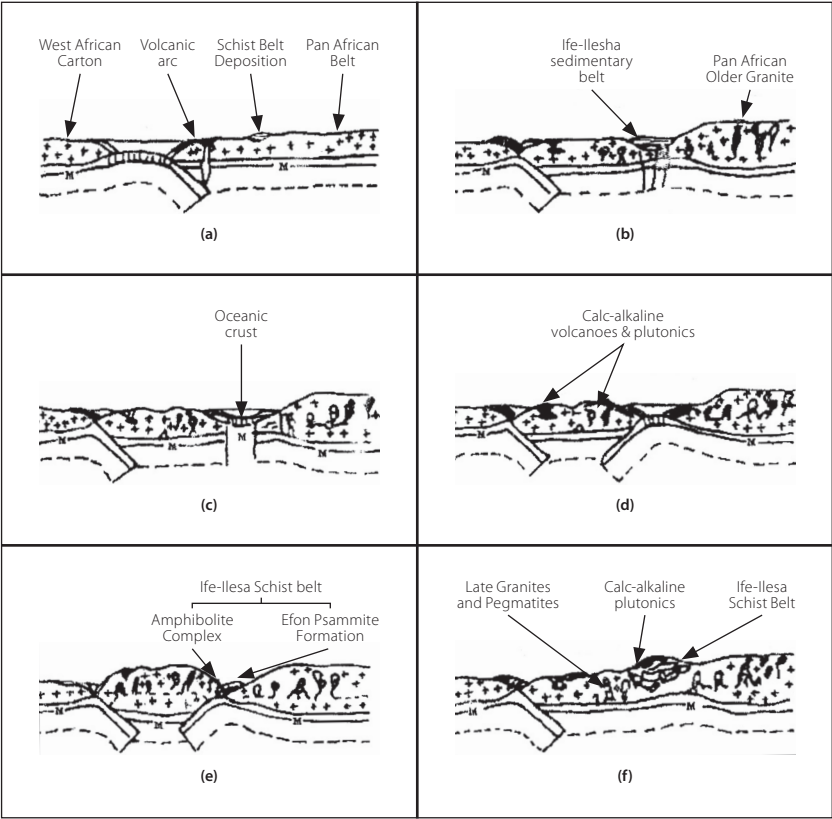
There are many schools of thought regarding the evolution of the Pan African and earlier mobile belts. One school of thought (Ogezi, 1977, Holt *et al.*, 1978, and Turner, 1983) proposes a purely ensialic process involving crustal thinning in response to crustal extension and continental rifting at the cratonic margin some 1000Ma ago leading to deposition of sediments in graben-like troughs floored by continental crust. The closure of the ocean at cratonic margin led to the deformation and metamorphism of the sediments and underlying basement resulting in the formation of the schist belts and reactivation of older basement during the Pan African orogeny. The second school of thought, the ensimatic model (Holt, 1982, Fitches *et al.*, 1985, Ajibade, *et al.*, 1987, Rahaman *et al.*, 1988) is a model involving the formation of marginal back-arc basins that accepted sediments. The closure of these basins led to the deformation and metamorphism of the sediments and reactivation of older basement. Ife-Ilesha schist belt is crucial in the latter model because it is associated with abundant mafic to ultramafic

rocks usually referred to as the amphibolite complex unlike most Nigerian schist belts. Also based on geochemical evidence, Rahaman *et al.* (1988) concluded that these rocks have ocean floor basalt affinity, and therefore suggested that the closure of the ocean at the cratonic margin along an easterly dipping Benioff zone led to the creation of a narrow back-arc marginal basin that was floored by oceanic crust. The closure of this marginal basin at the end of the Pan African orogeny resulted in the deformation and metamorphism of the accumulated sediments and volcanics and the intrusion of calc-alkaline granitoids.

Burke *et al.* (1977), in a major review of sutures of the world invoked the doctrine of uniformitarianism and suggested that Wilson cycle – the cyclical process of ocean opening and closing – would have taken place throughout the geological record and considered that if Wilson cycle is the only process that operates, then any fold belt within a continent marks a place where an ocean has closed. In the light of the above discussion, a model involving the existence of proto oceans, which involved opening of the ocean and deposition of metasediments of pelitic to greywacke affinity in a quiet environment coupled with back-arc subduction is hereby proposed for the evolution of the study area. The sediments in the back-arc basin undergone low grade metamorphism and later evolved into the schists. Initial crustal thinning led to the emplacement of ultramafic to mafic rocks of ocean floor affinities. Because of the thrusting and gliding of the eastern flank over the western flank, series of nappes were developed. This led to crustal thickening and subsequent rejuvenation of pre-existing crust and the production and emplacement of Pan-African granites e.g the Imesi Ile/Igbajo pluton (see Figure 8). The eventual closure of the ocean generated a collisional suture along the benioff zone. Events to the west of Ilesha belt in Ghana, Togo and Benin may result in a failed rift system (aulacogen) and subsequent lateral intracratonic compression of the sediments. On the other hand, there may have indeed been the opening and closing of a small ocean-complete with olivine tholeiites and volcanics. The existence of a weathered ultramafic rock south east of Ilesha may, as suggested by Turner (1983), represent an Ophiolite zone marked by the Ifewara fault.

In terms of structural evolution, Boesse and Ocan (1988) recognised two phases of deformation within the Ife-Ilesha area. The first Phase (D_1) generated tight to isoclinal folds, while the second Phase (D_2) which is more complex produced folds of variable styles and large vertical fault zones. This study also revealed that metamorphism and deformation are two major geological processes that took place in the study area. The metamorphism led to the emplacement of the quartz veins and pegmatite dykes which intruded the migmatite at Babalola Hill, Erinmo. Further deformation produced mineralogical bands on the outcrops which are later folded. The

Figure 8 The Geodynamic Evolution of the Study Area
(After Olade and Elueze, 1979)



first episode of folding produced assymetric and overturned antiformal fold (see Figure 6). The massive quartzites found on the crest of the ridges are excellent structural markers of this deformation, while the second episode may likely be responsible for the vertical fault zones inferred on Figure 7.

CONCLUSIONS

The analysis of the geology and structure of the fold belt around Okemesi, using LANDSAT image of the area has been carried out. The studies show the versatility of satellite images in providing a synoptic view of mega structures and its usefulness in carrying out regional mapping of geologic features. It is also useful in detecting lineaments in all directions, unlike SLAR that suppresses lineaments, which are parallel to the look direction. LANDSAT images are generally better than SLAR in terms of resolution and dectability for reconnaissance survey especially when they are of the same scale.

It can be concluded that the satellite image interpretation of the structure and geology and ground truth of the area around Okemesi has really demonstrated the usefulness of remote sensing in the structural and geologic mapping of an area. It is expected that further research in this area will map out the nappe structures and provide clues to the trend of tectonic events in the study area and generate the model to explain its tectonic history. Also, geochemical exploration of the area is much recommended to evaluate metallic element mineralisation potentials of the area. This may involve remote sensing analysis using the spectra signatures of some minerals.

To generalise, the study has shown that remote sensing technology is a versatile tool which could be used for wider applications such as natural resources mapping of rocks and structures that are difficult to observe on the field due to the rugged nature of the terrain with in accessible forests. This is particularly beneficial for many African countries which have areas which are inaccessible by land for the field geological studies. The advances made in the remotesensing technology has made it cost effective for developing countries to make use of it for different applications. African countries should initiate integrated use of remote sensing technology by involving various user departments and agencies and also by creating necessary ground infrastructure including human resources. They should also negotiate with other developing countries in the South such as India that operate their own remote sensing satellites to provide free data or at low cost.

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Conclusion

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There have been a number of attempts to apply a national system of innovation by a number of states in Africa. It appears most of the application suffers from mimicry: It is not grounded in the reality of Africa. Failure to appreciate the empirical variation in Africa must change into the success of the grounded appreciation of the rich variety of the African realities. For example, many states apply a national system of innovation by assuming the nation is taken for granted. But in Africa the nation is not something that can be assumed to be unproblematic. The state drives the nation; it is not the nation that drives the state. Any copying of a national system of innovation for 54 states is problematic.

New ways must be found how to apply without copying a national system of innovation: Should it be introduced in the current fragmented states, or should it be used to overcome the limitation of the current fragmentation by conceptualising an integrated African national system of innovation?

A key example is the difference between the South African systems of innovation and the fragmented states in the rest of Africa. In South Africa it is plausible to assume a national system of innovation exists. But even in South Africa the systems of innovation are bifurcated; and an empirically grounded appreciative research to discover the peculiarities of the system of innovation is critically important to undertake. If indeed the national systems of innovation can only be assumed and is not yet proved for the most developed African country such as South Africa, one can imagine what it means for all the other African states with low incomes.

One major problem is to explore each of the systems (if they exist) in each African state. Another is to find how a well-developed African system can interlink with other systems.

One way to generate rigorous research is to examine critically the South African system of innovation. An important research programme that can interlink the South African system of innovation with the fragmented

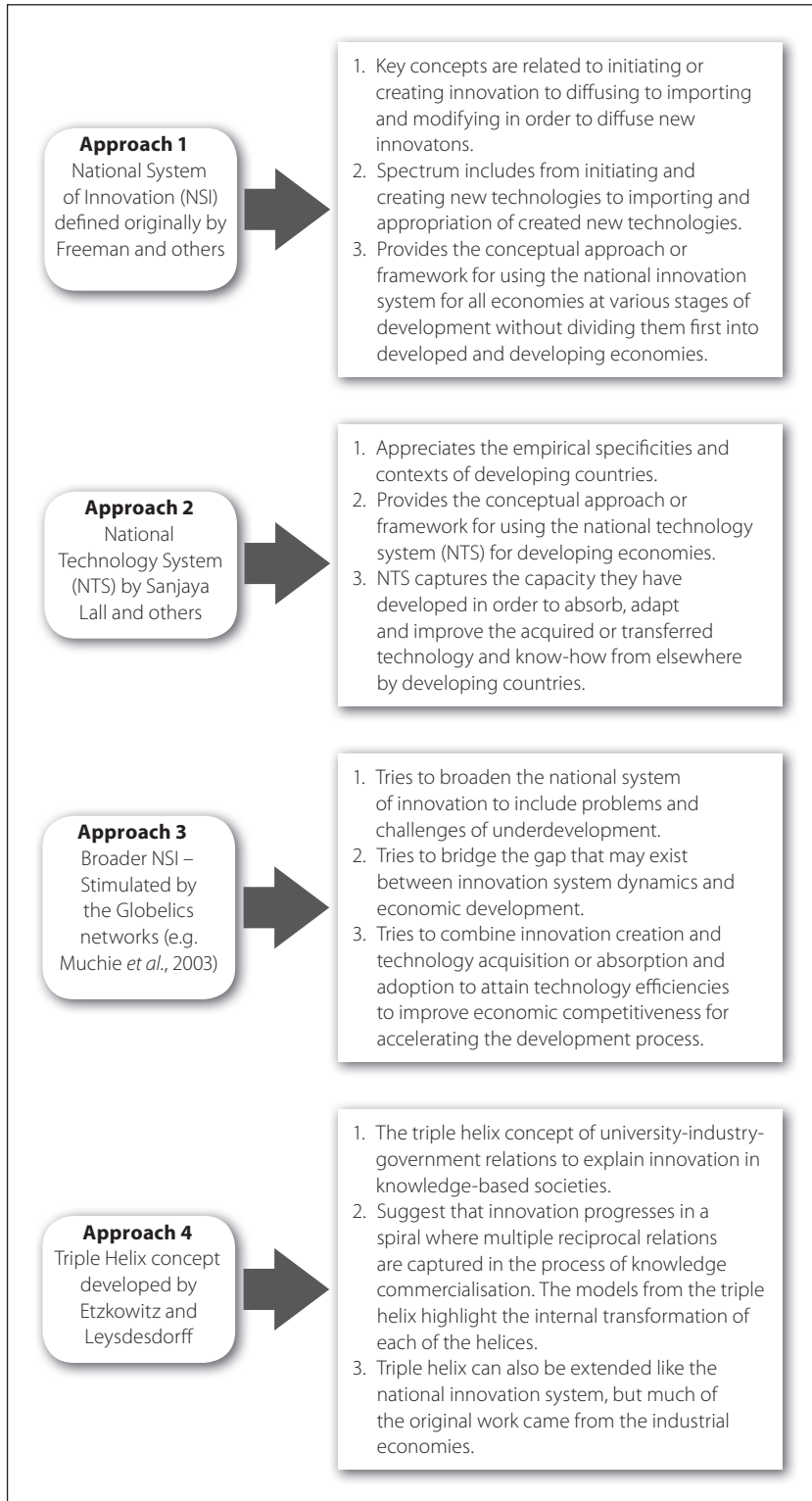
economies in the rest of Africa is needed. The effort to bring a structural transformation of the overall African economy requires discovering ways to link it with the relatively better developed South African system of innovation. There is still a big challenge to bring about the structural transformation of the overall African economy in efforts to build integrated, unified, networked systems of innovation in Africa through the application of science, technology, innovation and engineering.

Africa as a unified continent is still an entity that has not been fully realised. The African interrelated systems are, as a result, still in its nascent stage and are in a state of slow transformation. Innovation itself has many dimensions from the broad grassroots and community level to that driven by R&D. If we roughly classify the way innovation systems are evolving in Africa, there is no doubt that we have a differentiated picture where the interaction of the system of innovation characteristics is at different levels, quality and degree of existence. Such inequality calls for grounded appreciative research to establish the reality on the ground in order to facilitate the mapping and data collection of the overall direction and dynamics of the evolution of the making of an African national system of innovation.

At the moment, some critical opportunities are emerging in Africa. Most pertinent is the opportunity that opened up with South Africa assuming leadership of the Africa Union. It matters how this opportunity is translated to the advantage of the wider platform of nation states. The primary need is to concentrate on infrastructural networking, knowledge, economics and politics, standardisation and harmonisation in a sustainable manner. This will enable South Africa to provide policy advice to the AU and create the possibility of enhancing the AU activities across Africa.

The second is the opportunity for Africa to unite to explore space by itself rather than be a recipient of others' explorations as it has continued to happen without any break to date. The key example is the fact that the SKA, the square kilometres array radio telescope is now going to be driven in Africa by South Africa. The SKA is expected to be used to explore the spatial universe, the stars, galaxies, the dark matter and astrophysical processes. Knowledge related to unified field theory to understand not just how the universe works the way it does, but also why it works will be explored. This research and opportunity has now been won by South Africa's DST successful bidding. Now the real challenge is to get all of Africa behind this SKA exploration and for South Africa to welcome primarily other African states first before inviting others.

These new opportunities provide South Africa with the chance to initiate a strong effort to create a comprehensive African-wide system of infrastructure. Building infrastructure is not only technical capacity to network

Figure 1 Appreciative Approaches in the Innovation Studies Literature

infrastructure systems. It also includes the ability to create a fair political/economical system for networking. To date the African effort to interconnect with predictable and well-managed infrastructure has remained poor. It needs to change: Africa needs a networked road system. It needs a networked railway system. It needs a networked telecommunication system. It needs to develop a networked infrastructure that interlinks Africa by land, air, and sea making it easier for an African integrated economic system to evolve. It needs a unified African innovation system. The best way to start is to explore how South Africa can inspire the required unified system of African innovation, and at the same time create an inventory of how innovation system research has been undertaken in different African countries and economies.

The contributors have grappled with the way different states have attempted to apply a national innovation approach to explain the way innovation influences the interactions of the various actors, the policies and activities in the introduction of science, technology, innovation to bring about development and transformation. This research is still at its beginning. It opens up a Pandora's box of how to navigate the research landscape in the making of Africa's national systems of innovation.

Editors

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The most popularised concept in the economics of innovation literature has been the national system of innovation (NSI). It was in the late 1980s that the concept that Frederik List coined as the 'National Political Economy of Production' took off again with different thinkers writing about the peculiarities and distinctions of the Japanese, American, British, German, East Asian Tigers and other varieties of system construction. Freeman defines National System of Innovation as 'the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies.' Richard Nelson defines it as 'a set of institutions whose interactions determine the innovative performance of national firms. Lundvall defines the system of innovation as the 'elements and relationships which interact in the production, diffusion and use of new and economically useful knowledge and are either located within or rooted inside the borders of a nation state.' The normative assumption is that those nations that succeeded in building economic strength relied on the science, engineering, technology and innovation capability that made them to achieve an innovation advantage to put them ahead in the world, acquiring national or regional economic leadership as the case may be depending on what level of analyses is selected to look at particular failure, success or progress they made.

